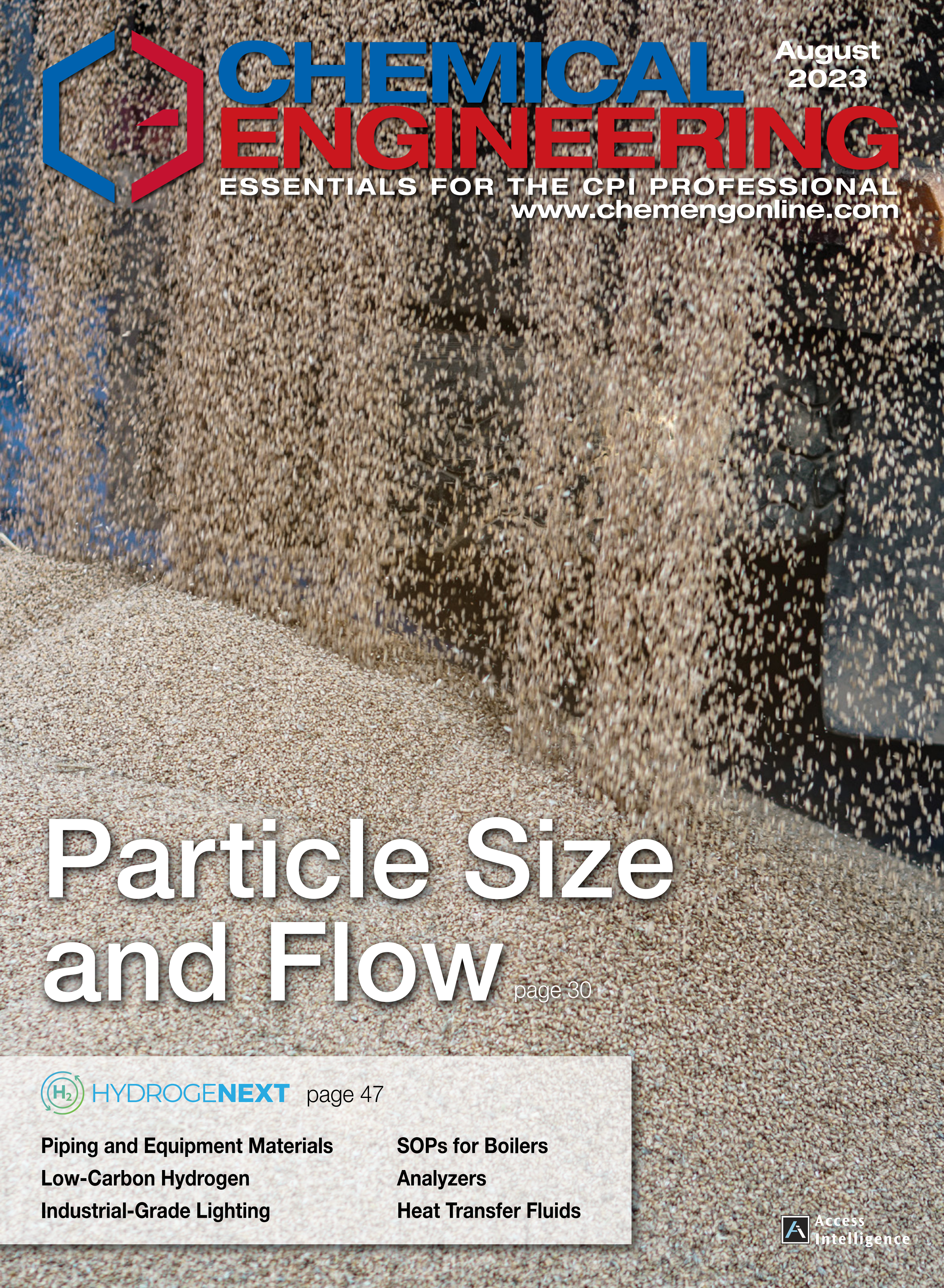

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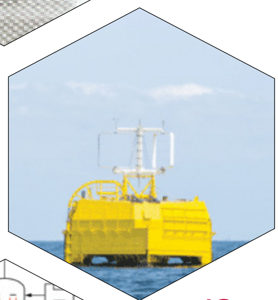
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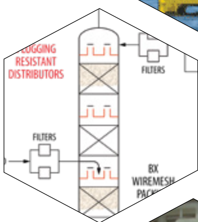

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Editor's Page

Digitalization progress and hurdles

At the 7th Connected Plant Conference, held June 25–28 in New Orleans, (CPC; www.connectedplantconference.com), attendees heard about significant progress made toward the digital transformation in the chemical process industries (CPI) along several fronts. However, complex challenges remain as organizations seek to take full advantage of available digitalization tools.

Engaging in digital transformation activities has become imperative for the CPI as they grapple with modern issues, such as decarbonization and environmental sustainability. The constant improvement, aggregation and re-combination of existing technologies, along with the advent of new technologies, will give rise to new opportunities to improve processes and workflows. Here are some of the topic areas discussed at CPC that we will be watching closely over the coming year.

People. The importance of company culture and worker buy-in framed many of the conversations at CPC. This year's conference theme "the intersection of technology, process and people," acknowledged the critical role that humans play in the way that digitalization tools are tested, implemented and scaled.

Data engineering. Turning available data into actionable insights is difficult. Contextualizing data and ensuring data quality are among the key challenges in any digital transformation initiative, because quality data sets form the foundation for the success of further analytics and artificial intelligence (AI) efforts. Questions around data quality and data ownership will continue to be important.

Cybersecurity. A holistic approach to maximizing efficiency across a whole process, plant or fleet requires the continued convergence of operational technology with information technology (IT) infrastructure. This increases the exposure of plant data to potential cyberattacks. Approaches to cybersecurity continue to evolve with the threat landscape.

Generative AI. Generative AI could have a massive impact on industrial operations if the industry can properly incorporate domain-specific knowledge into machine-learning models and effectively contextualize data for queries using natural language models.

Quantum computing. Computational chemistry will be an innovation driver in sustainability, and quantum computing, which uses quantum-physics concepts, such as superposition and entanglement, to approach computation probabilistically, rather than in a binary way, could change the way simulations are carried out. Quantum computing will not replace traditional computers, but will augment the capabilities of classical computers.

Digital twins. The use cases for digital twins, in which a digital version of a physical asset is used to gain optimization insights, are continuing to expand, and will have an even larger impact in the future.

Interoperability. Having control-system vendor software and hardware adhere to standardized, open control-system architectures will allow operators to access the best features and approaches for their specific digital transformation needs, and enhance the user experience for their workers. CPI workers of the present and future expect a positive and intuitive user experience, and approaches to pursuing the digital worker are increasingly people-focused.

Democratization. Machine-learning and data-analytics workflows can be time-consuming, so products are proliferating that allow partial automation of programming and data science, to allow a wider contingent of workers to use digitalization tools. ■

Scott Jenkins, senior editor

LINEUP

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Plant Watch

UBE to expand silicon nitride plant

July 13, 2023 — UBE Corp. (Tokyo, Japan; www.ube.com) plans to expand the silicon nitride production facility at its chemical complex in Ube, Japan. The facility is scheduled to go online in the second half of 2025. The production capacity will be increased by about 1.5 times the current level.

Toray to expand carbon-fiber plants in the U.S. and Korea

July 13, 2023 — Toray Industries, Inc. (Tokyo; www.toray.com) announced plans to increase regular-tow carbon-fiber production capacity at two facilities — in Spartanburg, South Carolina and Gyeongsangbuk-do, South Korea. These investments will increase the Toray Group's production capacity for these products by over 20% to 35,000 metric tons per year (m.t./yr) beginning in 2025.

Rio Tinto and Sumitomo to build hydrogen pilot plant in Australia

July 13, 2023 — Rio Tinto Ltd. (London; www.riotinto.com) and Sumitomo Corp. (Tokyo; www.sumitomocorp.com) will build a first-of-its-kind hydrogen plant in Gladstone, Australia, as part of a $76-million program aimed at lowering carbon emissions from the alumina refining process. The program plans to demonstrate the viability of using hydrogen in the calcination process. The project involves construction of a hydrogen plant at the refinery.

Johnson Matthey to build a production plant for catalyst-coated membranes

July 12, 2023 — Johnson Matthey plc (JM; London; www.matthey.com) plans to build a new catalyst-coated membrane (CCM) production facility in Shanghai to support the manufacture of electrolyzers for hydrogen production. The plant is due to be operational in 2025.

Saint-Gobain to expand gypsum manufacturing plant in Florida

July 12, 2023 — Saint-Gobain S.A.'s (Courbevoie, France; www.saint-gobain.com) North American business will invest $235 million over the next two years to expand and modernize its gypsum manufacturing facility in Palatka, Fla., more than doubling the production capacity of the existing manufacturing plant.

Corbion to triple production capacity for acid-powder products

July 10, 2023 — Corbion N.V. (Amsterdam, the Netherlands; www.corbion.com) announced that a new production line at the existing site in Spain will triple the company's capacity for producing acid-powder ingredients. The new production line, with capacity more than twice that of Corbion's current acid-powder production in Gorinchem, the Netherlands, is expected to be online sometime in the second half of 2025.

Alpla Group expands recycling plant in Poland

July 10, 2023 — Alpla Group (Hard, Austria; www.alpla.com) announced the expansion of its recycling plant in Radomsko, Poland. The annual production capacity will increase from 30,000 m.t./yr to 54,000 m.t./yr of food-grade polyethylene terephthalate (PET). The expanded Radomsko plant is one of the largest recycling plants for this material in Europe.

BASF opens co-located battery production and recycling center

June 29, 2023 — BASF SE (Ludwigshafen, Germany; www.basf.com) opened Europe's first co-located center for battery material production and battery recycling in Schwarzheide, Germany. The facility produces cathode-active materials and also includes a battery-recycling plant for the production of black mass. The new plant is the first production facility for high-performance cathode-active materials in Germany.

Grupa Azoty launches polypropylene production at Polimery Police

June 27, 2023 — Grupa Azoty S.A. (Tarnów, Poland; www.grupaazoty.com) has launched production of polypropylene (PP) at its Polymery Police site, one of the largest projects in the European chemical industry. The new plant will produce 437,000 m.t./yr of polypropylene and 429,000 m.t./yr of propylene.

AGC to increase production capacity for spherical silica

June 27, 2023 — AGC, Inc. (Tokyo; www.agc-chemicals.com) announced that its subsidiary AGC Si-Tech Co. is increasing production capacity for Resifa Sunsphere, a spherical silica product used in cosmetic products. At the company's Wakamatsu plant, facility expansion will be implemented to increase production capacity by approximately 1.5 times that of the current level. Operations are scheduled to begin in the second quarter of 2025.

Kraton expands manufacturing for styrenic block copolymers in France

June 27, 2023 — Kraton Corp. (Houston; www.kraton.com) announced the expansion of its manufacturing capabilities in Berre, France to produce renewable styrenic block copolymer (SBC) products. The new SBC production capabilities enable up to 100% certified renewable SBC to be produced.

Mergers & Acquisitions

ExxonMobil to acquire CCUS firm Denbury

July 13, 2023 — Exxon Mobil Corp. (Houston; www.exxonmobil.com) agreed to acquire Denbury Inc. (Plano, Tex.), a developer of carbon capture, utilization and storage (CCUS) solutions and enhanced oil recovery. The acquisition is an all-stock transaction valued at $4.9 billion. The acquisition of Denbury provides ExxonMobil with the largest owned and operated CO_2 pipeline network in the U.S., at 1,300 miles.

Borealis to acquire Italian polypropylene recycler Rialti

July 10, 2023 — Borealis Group (Vienna, Austria; www.borealisgroup.com) has signed an agreement to acquire Rialti S.p.A., an Italian polypropylene compounder and recycler. Based near Varese, Italy, Rialti focuses on mechanically recycled PP feedstock from post-industrial and post-consumer waste. The company has production capacity to make 50,000 m.t./yr of injection-molding and extrusion-based PP compounds.

LyondellBasell completes acquisition of Mepol Group

July 10, 2023 — LyondellBasell Industries N.V. (Rotterdam, the Netherlands; www.lyondellbasell.com) has completed the acquisition of Mepol Group, a manufacturer of recycled high-performance technical compounds located in Italy and Poland. Mepol S.r.l. and its subsidiaries Polar S.r.l. and Industrial Technology Investments Poland Sp. z o.o. will be subsidiaries in LyondellBasell's Advanced Polymer Solutions (APS) business unit, which produces polypropylene compounds, engineered plastics, masterbatches, engineered composites and more.

Evonik acquires Argentinian biotechnology firm Novachem

July 10, 2023 — Evonik Industries AG (Essen, Germany; www.evonik.com) has acquired Novachem, an Argentinian manufacturer of sustainable active ingredients used in the cosmetics, skincare and haircare industries. Novachem will be integrated into Evonik's Care Solutions business line within its Life Sciences division.

BASF and thyssenkrupp Uhde cooperate on NOx abatement

June 27, 2023 — Thyssenkrupp Uhde GmbH (Dortmund, Germany; www.thyssenkrupp-uhde.com) and BASF are cooperating on the marketing and further development of catalyst and process design for the abatement of emissions from N_2O and oxides of nitrogen (NOx). As part of the partnership, BASF is supplying catalysts for thyssenkrupp Uhde's EnviroNOx process technology.

Sasol and Topsoe forming JV for SAF production

June 22, 2023 — Topsoe A/S (Lyngby, Denmark; www.topsoe.com) and Sasol Ltd. (Johannesburg, South Africa; www.sasol.com) have signed a landmark agreement to establish a 50/50 joint venture (JV) to develop, build, own and operate sustainable aviation fuel (SAF) plants, and market SAF products derived primarily from non-fossil feedstock, utilizing green hydrogen, sustainable sources of CO_2 and biomass. ■

Mary Page Bailey

In-Service Heat-Transfer-Fluid Testing

Department Editor: Scott Jenkins

Regular heat-transfer-fluid monitoring can prevent fluid problems that lead to equipment failure, costly downtime and repairs. Parameters to watch include viscosity, acid neutralization number, moisture, solid or residue content, thermal degradation and flash point. This one-page reference provides information on how to examine these parameters. Representative industry standards are cited with the understanding that comparable BS (British Standard) or DIN (German Institute of Standardization) standards could also be used.

Viscosity

Viscosity value is unique to each fluid and is typically measured at 100°F or 40°C using the industry standard method ASTM D-445. The test can be run in a temperature-controlled bath with calibrated glass capillary viscosity tubes using elapsed time of fluid flow through the tube. Or, the test can be carried out using a Stabinger viscometer, where the kinematic viscosity is calculated by dividing the measured dynamic viscosity by its density. With use, fluid viscosity can shift based upon changes from degradation or contamination.

Acid number

New organic fluids typically have acid numbers of near zero milligrams of KOH per gram of sample. The analysis can be done by potentiometric titration using ASTM D-664. The acid number is found by dissolving some fluid in a mixture of toluene and isopropyl alcohol containing a small amount of water, and then titrating potentiometrically with alcoholic potassium hydroxide to an endpoint pH of 11. An alternative method is to use a color indicator and make the determination calorimetrically. The acid number value can increase with acidic contamination or from heated fluid oxidation.

Moisture

Analysis for moisture concentration in organic fluids can be done by volumetric Karl-Fischer titration using ASTM E-203. Water content is found by titrating the fluid with standard Karl-Fischer reagent to an electrometric endpoint. The method applies to fluids with moisture content in the range of about 50–1,000 parts per million (ppm). A second method is coulometric Karl-Fischer titration per ASTM D4928 in a range of 0.005 to 0.02 mass percent. Moisture in high-temperature heat-transfer-fluid service must be kept low to avoid short-term operational and long-term corrosion concerns.

Solids or residue content

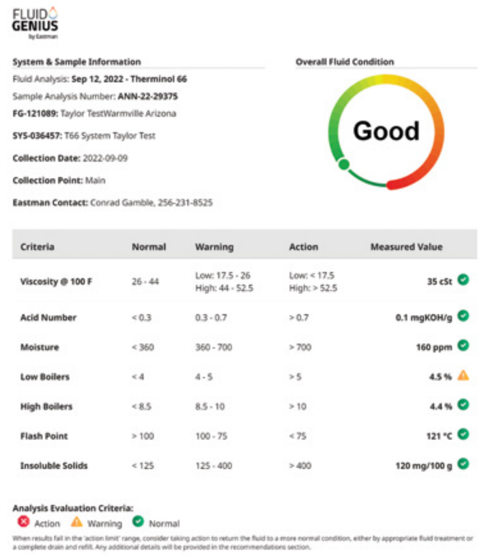
Measurements of solids content can be done by gravimetric separation and quantification of solids (mass) per unit volume of fluid filtered. A second method involves bulb distillation of a fluid sample under extreme vacuum with temperature increasing to 250°C until only non-volatile residue remains. The mass percent of non-volatile residue of fluid is reported. A third technique, known as Conradson Carbon Residue and described in ASTM D189, is sometimes performed to quantify carbon residue in mass percent remaining after evaporation and pyrolysis of an oil sample. This quantity can be an indicator of coking potential of an oil.

Thermal degradation

With measurement by simulated distillation gas chromatography using ASTM D-7213, the oil boiling range can be compared with that of unstressed (that is, unused) fluid to quantify the percentage of low-boiling and high-boiling degradation products present. Critical to accuracy is knowing the boiling range of the same fluid in its unstressed condition.

Flash point

Flash point temperatures are measured using ASTM D-92 (Cleveland Open-cup; COC) or ASTM D-93 (Closed-cup; CC) techniques, reported in Fahrenheit or Celsius. Comparison to the flash point temperature of the unstressed fluid standard can determine the change in fluid condition.



Criteria	Normal	Warning	Action	Measured Value
Viscosity @ 100 F	26 - 44	Low: 17.5 - 26 High: 44 - 52.5	Low: < 17.5 High: > 52.5	35 cSt
Acid Number	< 0.3	0.3 - 0.7	> 0.7	0.1 mgKOH/g
Moisture	< 360	360 - 700	> 700	160 ppm
Low Boilers	< 4	4 - 5	> 5	4.5 %
High Boilers	< 8.5	8.5 - 10	> 10	4.4 %
Flash Point	> 100	100 - 75	< 75	121 °C
Insoluble Solids	< 125	125 - 400	> 400	120 mg/100 g

Analysis Evaluation Criteria:
Action Warning Normal
When results fall in the 'action limit' range, consider taking action to return the fluid to a more normal condition, either by appropriate fluid treatment or a complete drain and refill. Any additional details will be provided in the recommendations section.

FIGURE 1. Analysis of heat-transfer-fluid parameters, such as acid number, viscosity and solids content, can help identify changes to fluids that are in operation, and determine if action should be taken

Knowing what the fluid is like in an unstressed condition can help determine what should be done to improve fluid condition. From this analysis, engineers familiar with the fluid's operating environment can assess what caused the changes and decide on what should be done. Since expertise at a general-service oil-testing laboratory can be more limited, a more detailed understanding of the test results and related action-thresholds, as they apply to specific fluids, is available from the manufacturer (Figure 1). For more on interpreting results, see Ref. 1. For coverage beyond the above tests, see Refs. 2 and 3. ■

Editor's note: Content for this column was authored by Conrad Gamble, Eastman heat transfer fluids

References

1. Gamble, C. and Schopf, M., Optimizing heat transfer fluid performance: How to avoid costly consequences, Eastman Chemical Co., white paper, www.eastman.com, 2015.
2. ASTM International, ASTM Standard D5372-20: Evaluation of Hydrocarbon Heat Transfer Fluids, ASTM International, www.astm.org.
3. Deutsches Institut für Normung e.V. (DIN) DIN 51529 – Testing of mineral oils and related products: Testing and evaluation of used heat transfer fluids, www.din.de.

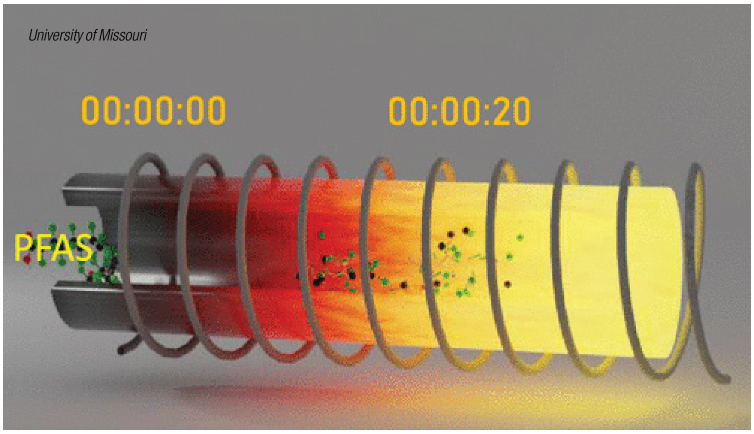
New heating method tackles PFAS contamination on spent treatment media

There are several established technologies to remove per- and polyfluoroalkyl substances (PFAS) from water, including membranes and adsorbents. However, such purification media can pose disposal challenges due to the potential for further PFAS contamination stemming from the spent media. Now, a new treatment technology developed by researchers at the University of Missouri (Columbia, Mo.; www.missouri.edu) targets the removal of PFAS from solid surfaces, such as the filters, resins and other media used for water treatment.

"Our technology employs flash or rapid heating to destruct PFAS. The key equipment is an induction heater paired with a metallic reactor (diagram). This method can be applied to treat PFAS-contaminated solid materials, such as soil, spent adsorbent media from water-treatment processes and solid waste," explains Feng Xiao, associate professor of civil and environmental engineering. Leveraging the Joule heating effect, this method degraded 98% of PFAS present on treated media surfaces, including granular activated carbon and anion-exchange resins, in just 20 s. The team has verified the technology at the laboratory scale and is currently seeking partners to persue pilot-scale operation and testing in municipal-waste treatment systems.

Breaking down PFAS using induction heating can lead to hydrogen fluoride (HF) as a byproduct, which will require an additional abatement step. However, the team points out that the presence of HF actually encourages the PFAS decomposition reaction.

So far, the work has primarily focused on the degradation of PFAS on spent media — specifically granular activated carbon and resins using induction heating — but Xiao believes the potential for additional treatment applications is promising. "We have collected substantial data illustrating that this technology is equally effective at degrading PFAS in soil. We are currently preparing a separate paper discussing its efficacy on contaminated soil," he adds.



Observing particle concentrations and velocities inside a fluidized bed

Fluidized beds are used in a variety of industries for combustion, drying, catalytic cracking and other processes. However, the process that occurs inside a fluidized bed is extremely complex and — due to a lack of effective measurement techniques — has remained largely unknown. Now, researchers from Chalmers University of Technology (Gothenburg, Sweden; www.chalmers.se) have developed a high-frequency radar technique that can measure exactly how particles behave in fluidized beds with unrivaled precision.

The radar transmitter and receiver convert lower frequencies into extremely high frequencies (up to 340 GHz), which can then be transmitted through the horn antenna. A gold mirror (an off-axis parabola) is used to redirect the beam toward the fluidized bed, enabling very precise measurements with high resolution in space and time.

As described is a recent issue of *Fuel*, this new terahertz-radar technology was demonstrated in a 3-m-high circulating fluidized-bed boiler. The technique can penetrate the reactor from the outside and measure the behavior of the particles inside it without disturbing the flow. The radar technique can also measure the velocity and concentration of the solid particles simultaneously with great precision and high resolution in time and space. This means that even minimal changes in the flow can be detected in real time, which is important when monitoring and controlling industrial processes.

Edited by:
Gerald Ondrey

ISOPROPANOL

Cepsa Química, S.A. (Palos de la Frontera, Huelva, Spain; www.cepsa.com) is constructing the first production plant to produce isopropyl alcohol (isopropanol), from renewable or circular materials, which the company says will make it the most competitive, innovative and environmentally friendly facility of its kind in the world.

The new €75-million plant will be operational in 2025 and will be located at Cepsa's chemical plant in Huelva. The integration of the new facility into the Andalusian Green Hydrogen Valley, which the La Rábida Energy Park in Huelva is part of, will allow the plant to be supplied with "green" hydrogen produced by Cepsa, taking advantage of the economic and financial synergies with the rest of the company's commercial and logistical structures and enhancing the sustainability of the associated industrial processes. All of the energy to be used in the new isopropanol plant will come from renewable sources, which means that the production of this product will be CO_2 neutral.

CO_2-BASED POLYMERS

Avantium N.V. (Amsterdam, the Netherlands; www.avantium.com) has partnered with SCG Chemicals Public Company Ltd. (SCGC; Bangkok, Thailand; www.scgchemicals.com) to further develop CO_2-based polymers and to scale-up to a pilot plant with an indicative capacity of 10 metric tons per year (m.t./yr).

One of Avantium's innovative technology platforms, called Volta Technology, uses electrochemistry to convert CO_2 to high-value products and chemical building blocks, including glycolic acid. By combining glycolic acid with lactic acid, Avantium can pro-

(Continues on p. 12)

duce polylactic-co-glycolic acid (PLGA), a carbon-negative polymer with valuable characteristics: it has an excellent barrier against oxygen and moisture, has good mechanical properties, is recyclable and is both home-compostable and marine-degradable. This makes PLGA a more sustainable and cost-effective alternative to, for example, non-degradable, fossil-based polymers, the company says.

Under this agreement, Avantium and SCGC intend to further evaluate PLGA in order to subsequently scale up production of glycolic acid monomer and PLGA polyester in the next two years to a pilot plant.

TEXTILE DYEING

Archroma (Pratteln, Switzerland; www.archroma.com) and Somelos Group (Ronfe, Braga, Portugal; www.somelos.pt) have joined forces to advance sustainable cotton processing with a new water-saving dyeing and finishing process that generates no wastewater.

Conventional cotton dyeing and finishing requires substantial water and chemical inputs and produces a large volume of wastewater. To address this challenge, the companies have developed the New Dry Dyeing/Ox Finishing Process for the production of bottoms and shirting in cotton fabrics. Based on Archroma's Pad-Ox dyeing process, which combines oxidation and fixation into one step, and the latest technologies for washdown effects, including ozone and laser treatments, it delivers water savings of up to 97% compared to conventional cotton dyeing and finishing.

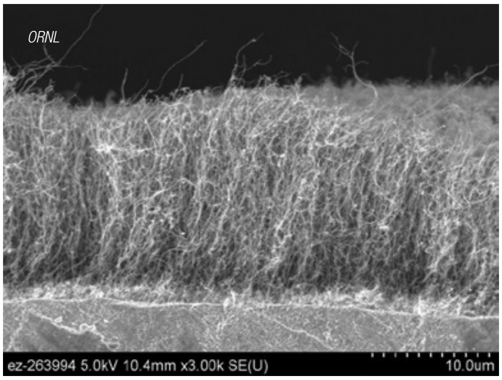
The New Dry Dyeing/Ox Finishing process only uses water to prepare the dye and oxidation baths. Archroma Diresul RDT liquid pre-reduced sulfur dyes ensure easy washdown and direct fixation — with no need for pre-washing —

(Continues on p. 14)

Carbon nanotube coating could expand the applications for superlubricity

When a sliding interface experiences a coefficient of friction (CoF) below 0.01, the situation is said to have superlubricity. In the past, superlubricity has been limited to the microscale in controlled environments, and to ceramic surfaces with polar-fluid lubrication. Now, research from Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov) demonstrates a path to expand superlubricity to the most common bearing system — steel-steel contact in non-polar oil lubrication. By dramatically decreasing friction in steel bearings and other steel-steel moving parts, energy consumption would be substantially reduced and equipment lifetimes lengthened because of less equipment wear.

The ORNL team, led by Jun Qu, first



developed a process for growing carbon nanotubes (CNTs) on a stainless-steel surface using a chemical vapor deposition process (see image). The vertically aligned CNTs are hollow, made from layers of rolled graphene. When steel with the CNTs on its surface moves past another steel surface, fragments of graphene flakes are shaved from the vertical CNTs and redeposited on the contact surface. These fragments form a graphene-rich tribofilm that is capable of reducing friction between the surfaces to almost zero. As the fractured carbon nanotubes release pieces of graphene, the graphene pieces are "smeared and connected to the contact area... then both contact surfaces are covered by some graphene-rich coating. Now, when they rub each other, it's graphene on graphene," Qu says.

The CNTs then function as a sacrificial lubricant reservoir, allowing the low-friction graphene to persist. The superlubricity of the ORNL coating has persisted in tests for more than 500,000 rubbing cycles. The team published its results in a recent issue of *Materials Today Nano*.

The presence of a small amount of polyalphaolefin (PAO) lubricant oil is crucial to achieving superlubricity. "The reason is, without oil, friction removes the carbon nanotubes too aggressively. Then the tribofilm cannot form nicely or survive long," Qu says.

Electrochemical amalgamation effectively removes mercury from concentrated H_2SO_4

It is well known that mercury is not only toxic, but is also highly mobile. As a result, Hg emissions from both industrial processes (gold mining, combustion of fossil fuels, cement production, waste incineration and more), as well as natural emissions (volcanic and geothermal activities) eventually are taken up by organisms in the food chain.

Existing methods for removing Hg from aqueous streams, such as precipitation, ion exchange and solvent extraction, either require the addition of chemicals and subsequent generation of large volumes of contaminated solids, or are limited to either very low or very high concentrations or feed volumes, which hampers their general application. And none of the conventional methods can handle highly acidic aqueous solutions, which are common in some metallurgical processes.

Five years ago, researchers at Chalmers University of Technology (Gothenburg, Sweden; www.chalmers.se) demonstrated an alternative decontamination method that is suitable for both low and high concentrations of mercury, and can reduce the mercury levels "far below" the limits allowed in drinking water, as reported in *Nature Communications* (see *Chem. Eng.*, January 2019, p. 8). The method uses a platinum cathode, which, when a potential is applied, extracts the mercury ions from solution to form a stable PtHg4 alloy. In addition to a high removal capacity (>88 g Hg per cm^3), the electrodes can easily be regenerated.

Now, the electrochemical amalgamation method has been demonstrated for removing mercury from concentrated acid from a zinc smelter. In both laboratory (50-mL volume) and pilot tests (20-L volume), more than 90% of the initial mercury content was removed from the smelter sample, achieving high-purity acid with mercury well below (0.02 mg/kg) the industrial limits of 0.08 mg/kg (after 80 h). The study, described in a recent issue of *ACS ES&T Engineering*, demonstrated the scalability of the technology.

delivering shorter processing, cleaner production and high wash-fastness.

ALUMINUM

Norsk Hydro ASA (Oslo, Norway; www.hydro.com) recently produced the world's first successful batch of aluminum using "green" hydrogen to replace natural gas as fuel for the recycling of aluminum. The test was carried out at a casthouse in Hydro's extrusion plant in Navarra, Spain. The test was conducted and led by hydrogen experts from Hydro Havrand, Hydro's green hydrogen company, in partnership with Fives Group (Paris, France; www.fives-group.com), an industrial engineering group with expertise in hydrogen-burner technology and solutions for the aluminum industry. Fives has contributed with design, and supplying of key components and controls needed to operate safely and effectively.

"This test is part of developing commercial fuel switch solutions and to demonstrate that hydrogen can be used in aluminum production. Green hydrogen can remove hard-to-abate emissions from fossil fuels, in processes where electricity is not an alternative, both in the aluminum industry and in other heavy industries," says Per Christian Eriksen, head of Hydro Havrand.

SOLAR-THERMAL H_2

A joint project of Synhelion SA (Zurich, Switzerland; www.synhelion.com) and the University of Florida (UF; Gainsville; www.ufl.edu) has been awarded \$2.7 million from the U.S. Dept. of Energy Solar Energy Technologies Office (SETO). The project aims to enable large-scale production of "green" H_2 from solar energy by leveraging concentrating solar power (CSP) infrastructure and solar heat to split water into H_2 and O_2.

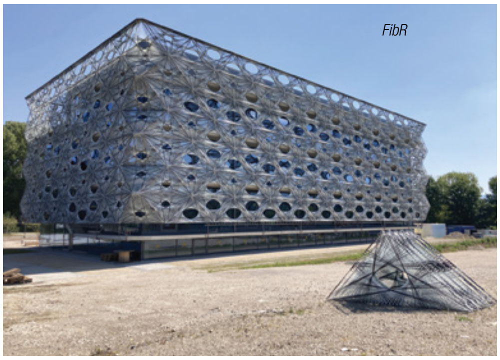
Synhelion's technology delivers high-temperature

(Continues on p. 15)

This fiber technology could revolutionize building construction

With the Texoversum (photo), Reutlingen University (Germany; www.reutlingen-university.de) has put into operation a training and innovation center for the textile industry that is unique in Europe. The almost 2,000-m^2 textile-like façade of the new building combines the innovative power of this industry with the 160-year tradition of Reutlingen as a textile location. The highlight: The components were wound from fibers that are fixed with a special plastic resin developed by Covestro AG (Leverkusen, Germany; www.covestro.com).

The façade of the Texoversum is just one example of a new technology that could completely revolutionize the construction industry. The sophisticated structure was designed on the computer and is based on carbon fibers wound by robots. Similar to networks in nature, for example in spider webs, beetle wings or palm leaves, the fiber structures are also very lightweight, but at the same time highly resilient, and require very little material. This not only saves resources, but also facilitates transport and assembly of the components.



FibR

The co-inventor of the innovative technology is architecture professor Moritz Dörstelmann, whose company, FibR GmbH (Kernen, Germany; www.fibr.tech), also realized the façade of the Texoversum. "In contrast to conventional steel and concrete structures, we are able to get by with a minimum of material, because the robots only process as many fibers as are needed for the strength of the respective structure," he explains. "As a result, we also save large amounts of CO_2 emissions." Dörstelmann also sees advantageous applications for the technology in roof structures, supports and, not least, interior fittings.

The necessary strength and durability of the composite is provided by Covestro's aliphatic polyurethane resin system Desmocomp, in which the fibers are embedded as if in a matrix. "The resin is highly resistant to weathering and the sun's high-energy ultraviolet (UV) radiation, making it very suitable for outdoor applications," explains Pejman Norastehfar, architect and specialist for construction applications in Covestro's Coatings and Adhesives segment. "Other plus points in the construction sector are its excellent chemical and flame resistance."

The building provides approximately 3,000 m^2 of space for workshops, laboratories, a textile collection, think tank space and classrooms. The costs for the construction of the Texoversum (€18.5 million) were borne by the employers' association Südwesttextil, whose members include FibR.

New solvents derived from biomass

Last month, Circa Group A/S (Oslo, Norway; www.circa-group.com) applied for patents for two new solvents for CO_2 capture processes. The solvents, named Furatech:1 and Furatech:2, were developed over the last 12 months as part of the company's platform molecule, levoglucosenone (LGO), which is produced from waste biomass using the company's Furacell process. The new Furatech solvents have been designed to be used in several current CO_2-capture processes, and discussions are underway about further optimization with engineering partners.

"Applying for patents is a major step and we are sufficiently excited about the performance of these two new CO_2 solvents that getting protection in place as quickly as possible is a priority," says Tony Duncan, Circa CEO. "Furatech testing has shown good CO_2-capture performance across multiple cycles, as well as lower energy requirements in the desorption phase compared to current industry standards."

In parallel with this work, Circa Group is also planning for the commissioning of the ReSolute plant, which is scheduled for mid 2024. The ReSolute project, funded by the French government, the E.U. Horizon 2020 research and innovation program and the Bio-based Industries Consortium, will scale up the current production process to 1,000 metric tons per year (m.t./yr) of the bio-based solvent, Cyrene, which is also derived from LGO (*Chem. Eng.*, May 2013, p. 12). The company aims to increase Cyrene production capacity to 80,000 m.t./yr by 2030.

New adsorbent removes radioactive cesium ions from nuclear wastewater

One of the major byproducts of the nuclear fission process used for power generation is ^{137}Cs, a radioactive isotope of Cs that has a half-life of 30 years and is often removed from nuclear-power-plant wastewater via selective adsorption using ion exchangers. However, this process is severely hindered in acidic wastewater where excess protons impair the adsorption ability and damage the lattice structure of the adsorbent.

Now, researchers from Pusan National University (Busan, South Korea, www.pusan.ac.kr) found a way to turn this adversity into an advantage. In their work, to be published in the August issue of the *Journal of Hazardous Materials*, they introduce potassium calcium thiostannate (KCaSnS), a new layered Ca^{2+}-doped chalcogenide ion exchanger. It utilizes the typically problematic H^+ ions in acidic wastewater to enhance the adsorption of Cs^+. Essentially, the Ca^{2+} ions from KCaSnS are leached out by H^+ and Cs^+ ions, making way for Cs^+ ions.

"Through a transformative approach, the troublesome proton was converted into a functional agent by incorporating Ca^{2+} into the Sn–S matrix, resulting in a metastable structure. Moreover, Ca^{2+} is a harder Lewis acid than Cs+ and can thus leave the lattice easily because of its weaker affinity to the Lewis soft base S^{2-} under acidic conditions. This provides a large enough space for Cs^+ to reside after its release from the lattice structure," explains Kuk Cho, professor at the Department of Civil and Environmental Engineering.

In the study, the team used a hydrothermal process to synthesize the KCaSnS ion-exchange material, which was then used to investigate the adsorption of a non-radioactive isotope of Cs^+ (to avoid radioactivity exposure) in different solutions with pH values ranging from 1 to 13. The team found that at pH 5.5, the Cs^+ ion-adsorption capacity was 370 mg/g, whereas at pH 2, the capacity increased by 68% to 620 mg/g. Remarkably, this trend was completely opposite to what previous studies had established.

A biomimetic process to make soft fibers for smart textiles

For intelligent textiles to function effectively, they need to be strong, stretchable and electrically conductive. However, fabricating fibers that possess these three properties has been challenging.

Drawing inspiration from how spiders spin silk to make webs, an international team of researchers has developed a method of producing soft fibers that possess these three key properties. The study — led by assistant professor Tan Swee Ching from the Dept. of Materials Science and Engineering under the National University of Singapore (NUS; www.nus.sg) College of Design and Engineering — was reported in a recent issue of *Nature Electronics*.

Conventional spinning methods to fabricate synthetic fibers require high pressure, high energy input, large volumes of chemicals, and specialized equipment. Moreover, the resulting fibers typically have limited functions. In contrast, the spider-silk-spinning process forms strong and versatile fibers at room temperature and pressure. Two unique steps in spider-silk formation were identified that the team could mimic. The first is the change of a highly concentrated protein solution (silk dope) into a strand of fiber. The second step identified was that the arrangement of proteins within the dope changes when triggered by external factors to help separate the liquid portion from the silk dope, leaving the solid silk fibers. The team recreated the two steps and developed a new spinning process known as the phase separation-enabled ambient (PSEA) spinning approach.

The soft fibers were spun from a viscous gel solution comprised of polyacrylonitrile (PAN) and silver ions (PAN-Sion) dissolved in dimethylformamide. When the gel is pulled and spun under ambient conditions, the soft fiber forms. When exposed to air, water molecules in the air cause the liquid portion of the gel to separate from the solid portion of the gel — a phenomenon known as the nonsolvent vapor-induced phase-separation effect. The droplets are simply removed by gravity. ■

solar process heat beyond 1,500°C, enabling the decarbonization of industrial processes and the production of sustainable fuels. For this project, Synhelion and UF will jointly develop a solar reactor powered by high-temperature solar-thermal energy to produce H_2 gas from water and sunlight. The H_2 produced can then be stored, transported, and utilized on demand, for example in transportation sectors that are focused on decarbonizing their industries. The project team will work to improve the efficiency and cost of solar thermochemical H_2 production by taking advantage of new redox materials that enable the chemical reactions in the reactor.

CARNOT BATTERIES

Carnot batteries, which temporarily store electricity as heat, are a promising technology for storing electricity generated by the sun and wind, without having to rely on the increasingly "precious" supplies of lithium used in Li-ion batteries. A Carnot battery consists of three components connected in series: a high-temperature heat pump, a heat-storage unit and a heat engine. The heat pump converts the electricity generated by sun and wind (but not immediately required) into heat, which is used to charge the storage unit. When the electricity demand increases, the heat engine discharges the storage unit, thereby converting the heat back into electricity.

Last month, a new project was launched to optimize working fluids used by Carnot batteries. The three-year, €298,000 project is being funded as part of the DFG Priority Program, and led by the Chair of Technical Thermodynamics and Transport Processes (LTTT) in the Center of Energy Technology (ZET) at the University of Bayreuth (Germany; www.uni-bayreuth.de).

"Initial demonstration plants show that high round-trip efficiency can be achieved with Carnot batteries: Up to 70% of the excess electricity fed into the grid from renewable energy sources can ultimately be recovered," explains Florian Heberle, research associate at the LTTT research group and managing director of the ZET. "The storage costs per kilowatt hour are in the range of pumped-storage power plants or electrochemical batteries."

The investigations will focus on special mixtures of natural hydrocarbons and unsaturated partially halogenated refrigerants. The aim is to precisely identify thermochemical properties, but also to test the fluids in practice. ❐

Low-Carbon Hydrogen: Considering Scale

The future of green hydrogen depends on the success of each stage of its ecosystem. Many factors are contributing to the critical infrastructure scaleup necessary to achieve industrial decarbonization

Globally, hydrogen is increasingly being considered as a critical part of industrial decarbonization strategies, both as an alternative fuel and as a method for decarbonizing manufacturing sectors that use hydrogen as a feedstock. Recently, incentives from the Inflation Reduction Act (IRA) have rapidly accelerated activity around low-carbon hydrogen projects in the U.S., aiming to increase the use of hydrogen as an energy source and the adoption of "green" hydrogen over traditional fossil-fuel-based "gray" hydrogen. As part of the IRA, significant funding from the U.S. Dept. of Energy (DOE; Washington D.C.; www.energy.gov) is being earmarked for Regional Clean Hydrogen Hubs — large-scale production and transport networks that will build out the full hydrogen value chain. These hubs include electrolyzers for producing green hydrogen from water, refueling stations for distributing it and fuel cells for converting it into electricity, as well as pipelines, tanks and other logistics infrastructure. Each hub has submitted a formal proposal, and funding selections will be announced later this year. As low-carbon hydrogen production proliferates throughout the U.S. and beyond, there are many critical factors being considered behind the scenes of this massive scaleup, including workforce concerns, hydrogen safety and storage, equipment supply chains and end use.

FIGURE 1. The supply chain for green hydrogen starts with the manufacture of electrolyzers and their associated components, including catalyst materials and membranes

Electrolyzer supply chain

With the influx of low-carbon hydrogen projects being announced, the manufacture of electrolyzers and associated components is rapidly scaling up, with focus on economies of scale and automation. Simultaneously, advances in energy efficiency and durability from higher-performing membranes and catalysts are reducing upfront capital costs. "Upscaling electrolyzer production is one of the biggest potential bottlenecks for ramping up the hydrogen market. A substantial production increase is based, in turn, on a massive expansion of renewable energy capacities. Strategic investments along the whole value chain are key to preventing a long-term production restriction," says Stefanie Kopchick, hydrogen business venture leader at The Chemours Company (Wilmington, Del.; www.chemours.com). Chemours is in a unique position as a manufacturer of electrolyzer components — namely, Nafion ion-exchange membranes — as well as a user of green hydrogen at some of its manufacturing sites. The company recently announced plans to invest $200 million to expand production capacities for ion-exchange materials at its plant in Villers-Saint-Paul, France, and is also partnering with TC Energy to install proton-exchange membrane (PEM) electrolyzers (Figure 1) to supply hydrogen for two Chemours manufacturing sites

FIGURE 2. In hydrogen fuel cells, several components work together to control hydrogen and ensure that fuel is dispensed correctly, including valves and regulators

in West Virginia as part of the Appalachian Regional Clean Hydrogen Hub (ARCH2) proposal. "To further advance the decarbonization of our manufacturing processes at each site, Chemours plans to consume a portion of the produced clean hydrogen as a blended fuel with natural gas to fire existing boiler equipment," adds Kopchick. To reach the hydrogen production capacities needed for industrial decarbonization, electrolyzer performance must continue to improve alongside manufacturing scale, particularly in terms of energy efficiency and durability of internal components. "We are constantly striving to increase the energy efficiency of our ion-exchange membranes, which have a direct impact on overall electrolyzer efficiency. At the same time, we are working to increase the durability of the membranes. Furthermore, lower costs can be achieved by reducing catalyst loading levels or shifting to alternative catalysts that don't decrease efficiency or durability. In this area, Chemours is continuing development of ionomer dispersions, which allow precious metal catalysts to be used more efficiently and last longer in these applications," says Kopchick.

Workforce

The Hydrogen Hubs are bringing together industry, academia and government bodies to take advantage of the unique geographic, workforce and infrastructural benefits of their respective regions. Because the hubs are focused on commercial-ready technologies, rather than testing conceptual or research-focused endeavors, the role universities take is generally focused on honing workforce skills and fostering beneficial relationships with the communities where the projects will actually be executed. "Universities have a very important sort of 'connective-tissue' role to help align our manufacturing alliances, our government agencies and other university partners into a cohesive community," explains Tim Filley, director of the Institute for Resilient Environmental and Energy Systems (IREES) at the University of Oklahoma (Norman; www.ou.edu), a partner in the HALO Hydrogen Hub (www.h2alo.org), a regional coalition between Arkansas, Louisiana and Oklahoma applying for funding from the DOE. "The hub is really about shovel-ready technologies, not R&D or pilot projects, so industries that have existing technologies that are ready to be put into the marketplace and scaled is what we're seeking. We're also thinking about the interface between local production and offtake," he adds.

A key consideration in the economics of a hydrogen hub is the ability to utilize existing infrastructure and natural resources, which obviously varies greatly from region to region. "The ultimate goal is a vibrant hydrogen economy across the value chain with clean production, clean storage and clean use. We are broad in our perspective, in terms of end users, and we are thinking about leveraging the strengths of the three states — you can imagine that these states have enormous strengths in the petrochemicals industry and access to vast natural-gas reserves, but we also have abundant resources that allow us to produce green hydrogen through electrolysis. Those electrons that we're using to produce hydrogen are going to come from various sources — from methane, as well as wind, solar and potentially nuclear power," says Filley.

But natural resources and physical infrastructure are not the only factors supporting a hydrogen hub proposal — there are also complex considerations related to workforce, education and environmental and economic impacts to local communities. The hydrogen hubs fall under the major infrastructure and energy projects that are adhering to the Justice40 federal initiative, which aims to decrease the burden on communities that are disproportionately affected by pollution and the impacts of climate change. "With the Justice40 executive order in mind, we're striving to progress environmental justice goals by thinking about diversity, equity, inclusion and accessibility, to ensure that benefits flow to those communities where we site the facilities," says Filley. "We're not just making sure we bring high-

FIGURE 3. Lhyfe's plant in Bouin produces up to 1,000 kg/d of green hydrogen via electrolysis

paying jobs locally, also we're looking at past burdens to the societies in those areas — energy burdens, environmental burdens, job burdens and how we can rectify some of that. We're connecting with social and manufacturing groups to build community-benefits plans, collaboratively," notes Filley.

Storage

The regional U.S. hydrogen hubs are being designed to take advantage of existing infrastructure, industrial sites, natural resources and geology. Obviously, these factors vary greatly from region to region, making the proposals unique slices of the country's energy landscape. A major piece of the puzzle is the region's plan for hydrogen storage.

There are a number of complex challenges in storing hydrogen, and the preferred storage options may vary vastly based on geography, from underground storage to specialized ceramic tanks to liquid carrier molecules. "There are challenges specific to hydrogen just because it's a much smaller, much more reactive molecule. For storage subsurface, we have to consider its geochemical reactivity, as well as how hydrogen is going to impact the microbial communities underground, and if that impact is going to cause loss of hydrogen inventory," explains Shadi Salahshoor, senior technical leader of the Hydrogen Technology Center at GTI Energy (Des Plaines, Ill.; www.gti.energy). GTI Energy is leading a number of research projects focused on hydrogen storage, with special focus on evaluating the subsurface storage of hydrogen in aquifers and depleted oil-and-gas reservoirs. "A key angle in subsurface storage is the compatibility of hydrogen with downhole equipment. There are ongoing projects researching hydrogen blending into pipelines that involve a great deal of pipeline and wellhead equipment that must be compatible with hydrogen," says Salahsoor. Hydrogen's diffusivity — another result of its small size — is another aspect to consider, as hydrogen can potentially diffuse through underground geologic formations, causing inventory loss or contamination.

GTI is a partner on the DOE's H2@Scale project in Texas, which can be thought of as a "proto-hub," since it is smaller in scale than the proposed regional hubs, but encompasses the entire hydrogen value chain in one project. "We have hydrogen production, storage and end-use all on site. Basically, we have an electrolyzer and methane reforming onsite producing hydrogen, which is utilized by a fuel cell," says Salahshoor. She notes that for this project, aboveground storage tanks are being used, but that for a larger-scale project, underground storage would be preferable due to the equipment footprint required for the necessary storage volumes. "If you want to store tons and tons of hydrogen, you might need a massive number of tanks, which can be really tricky to handle with all the safety and environmental aspects," she adds.

For the large-scale hydrogen projects being proposed, hydrogen producers must consider a somewhat different mindset than on smaller projects. "For decarbonizing industry, we need to start thinking about these hydrogen-storage needs on the same scale as natural gas. There aren't many commercial, or even pilot-scale projects now, but in the next 5–10 years, we are going to see several pilots showing the feasibility of different storage methods," emphasizes Salahshoor.

Currently, one of the most economically and technically feasible methods for long-duration, large-scale hydrogen storage is in underground geologic formations, explains Claire Behar, chief commercial officer of Hy Stor Energy LP (Jackson, Miss.; www.hystorenergy.com). Hy Stor is leading the Mississippi Clean Hydrogen Hub, reportedly the largest of the proposed hubs, which aims to utilize the state's significant volume of salt caverns for underground hydrogen storage. "The hub will bring together the production, storage and delivery of carbon-free hydrogen, but to really reach scale in a resilient fashion, we must focus on the geologic storage aspect. Mississippi really has geology and geography that is unparalleled globally. Not many locations have so much unutilized salt geology," says Behar.

The hub will couple the salt-cavern storage with electrolytic hydrogen production, using solely off-grid renewable-energy sources, including solar, onshore wind and geothermal power. For hydrogen delivery, there will be a dedicated hydrogen pipeline and planned truck transport, as well as transport access from the Mississippi River and nearby Gulf Coast ports. Furthermore, notes Behar, port access will enable the export of green hydrogen to international markets. "We're looking at decarbonizing the current industries in our region and some maritime transport, while also attracting new green manufacturing firms," she adds.

A major incentive for new parties to join the hub is support to demonstrate new technologies for electrolyzers and other critical components in the hydrogen supply chain. "We're creating a circular ecosystem where startups can come and prove their renewable technologies. They can test their run hours and durations outside the laboratory and take advantage of being connected to the salt cavern

FIGURE 4. The SeaLhyfe project is said to be the world's first offshore hydrogen-production pilot to begin operation

storage and a flexible, non-intermittent supply of hydrogen. It will be very exciting bringing these new renewable technologies to life."

Safe hydrogen handling

No matter how hydrogen is produced, it must be handled as safely as possible. It can be explosive when not handled properly, especially at the high pressures required for many transport and end-use options. "As it moves throughout the value chain, hydrogen is subject to pressures of up to 15,000 psi, and, like many fuels, can be explosive when not handled properly. To achieve a landscape that can effectively and safely meet demand, it is critical that companies identify technologies that can reliably and efficiently control hydrogen fuel, from production through end use. This requires high-pressure solutions across the hydrogen ecosystem," says Akilah Doyle, global product marketing manager at Emerson (St. Louis, Mo.; www.emerson.com). While the components for hydrogen storage and transportation have been well-demonstrated, large-scale electrolyzers and fuel cells require some additional safety and control considerations. "For an electrolyzer to work effectively and safely, the flow of water, hydrogen and oxygen, must be precisely controlled. Reliable valves, backpressure regulators and an intelligent programmable logic controller (PLC) can provide a high level of media control," explains Doyle. There are essentially four control layers in an electrolyzer that work in tandem to provide the control needed to ensure safe and efficient operation: the valves controlling media flow (including backpressure regulators and pneumatic shutoff valves); the actuation technology (including valve islands and solenoid pilot valves); the PLC; and the supervisory control and data acquisition (SCADA) system. Doyle notes that some valves in the system will require IP66 protection.

For fuel cells, the requirements are similar, but because hydrogen is the feed rather than the product, high-pressure storage is crucial as it helps to maximize system fuel usage. "The hydrogen storage tanks cannot be run to empty due to pressure constraints, so enabling efficient fuel delivery to the fuel-cell stack with minimal losses is critical. The system must be able to operate consistently across a range of operating modes — acceleration, deceleration, stopping and idling, which all require varying hydrogen flow demands. This stable system operation is aided through a design that employs positive, high-pressure fuel shutoff and is achieved through use of a reliable hydrogen regulator," says Paul Kondratyev, global product marketing manager at Emerson. Such regulators minimize the risk of leaks and can extend the lifecycle of fuel cells by ensuring they have an even amount of hydrogen dispersed across them while in use (Figure 2).

FIGURE 5. Construction has begun on the world's first dynamic power-to-ammonia plant, which will use electrolysis-based hydrogen as a feedstock

Green hydrogen in practice

Although there is much discussion about the ballooning production capacities of green hydrogen required for numerous upcoming decarbonization projects, there isn't as much discussion about the current state of operating green-hydrogen plants. French company Lhyfe (Paris; www.lhyfe.com), a "pure player" in the production and distribution of green and renewable hydrogen, started up a production facility in Bouin, Vendee, France in September 2021 that produces up to 1,000 kg/d of green hydrogen (Figure 3). "A unique aspect of this plant is that it sources seawater, so we don't take any water from the utility grid. We treat the seawater so that it is comparable to demineralized water for electrolyzer use," explains François Hoche, industry market manager at Lhyfe. Furthermore, he adds, the plant sources its renewable power directly from a nearby wind park, so it is essentially "behind the meter," meaning that it does not draw from the local power grid. The major hydrogen users for the site are in the mobility and logistics sectors. "One of the main customers of the facility is a logistics and distribution center operated by grocery chain Lidl. At this center, they have converted more than 120 forklifts to run on green hydrogen," says Hoche. At Lhyfe's site, produced hydrogen is compressed and loaded onto tube trailers for transport to users. "In order to transport as much hydrogen as possible, we compress the hydrogen and we have different sizes of containers that are used to distribute the hydrogen to the final customers. In what we call the 'small industry' market, users may consume only one or two containers per week, so we switch containers with each delivery, bringing a full one to site and taking an empty one back to the factory," he adds.

In addition to two under-construction plants in France, Lhyfe has also announced several other projects throughout Europe, including SeaLhyfe, located in the Atlantic Ocean off the coast of northwestern France, which is said to be the world's first offshore hydrogen-production pilot project (Figure 4). "When we talk about renewable hydrogen, it's important to realize that the dependence on renewable energy sources makes it crucial to look for the largest possible intensity of renewable power, but many sources have the inconvenience of being intermittent. So we're looking at offshore production to maximize energy intensity," says Hoche. In June, SeaLhyfe began production of offshore green hydrogen using a 1-MW electrolyzer capable of producing up to 400 kg/d of hydrogen. From September 2022 to May 2023, the SeaLhyfe module was moored in the Port of Saint-Nazaire. During this time, Lhyfe conducted a series of startup and validation tests to optimize system performance. The company also developed a software platform for remote management of the unit. Now, the SeaLhyfe unit has been towed 20 km offshore and connected to the site's subsea hub using an umbilical cable designed specifically for use in hydrogen applications. Following the success of SeaLhyfe, the company, as part of the HOPE consortium, has received a €20-million grant to commercialize a much larger 10-MW offshore green-hydrogen unit, capable of around 4 m.t./d of production.

Ammonia production is one of the most promising avenues for industrial decarbonization using green hydrogen. Not only is ammonia a much-needed commodity product for manufacture of fertilizer and other products, it also has great promise as a heavy-duty transport fuel and energy carrier for hydrogen itself. A recently announced project in Denmark is coupling electrolysis of water into green hydrogen with the production of ammonia, all powered by renewable energy, in what is being called the world's first dynamic, green "power-to-ammonia" plant. "We've been converting hydrogen into ammonia for decades, so we know how to handle it, and we know how to store it in a safe manner," says Jeppe Bentzen, business development director at ABB Energy Industries in Denmark (ABB; Zurich, Switzerland; www.abb.com) on the benefits of green ammonia. ABB is collaborating with project partners Skovgaard Energy A/S (Lemvig, Denmark, www.skovgaard.dk), Topsoe A/S (Lyngby, Denmark; www.topsoe.com) and Vestas (Aarhus, Denmark; www.vestas.com) on the new plant, called Renewable Dynamic Distributed Ammonia Plant (REDDAP), which aims to begin production in 2024 with an anticipated production capacity of 5,000 metric tons per year (m.t./yr) of green ammonia for fertilizer and marine fuels. Construction on the site is currently underway (Figure 5).

A notable benefit of dynamic power-to-X plants is that they make their product when conditions are positive — the sun is shining and the wind is blowing — and they can ramp down production when the energy source is not present, but this type of operation poses some specific challenges. "The groundbreaking part of this project is that it's the first power-to-ammonia project that is running in fully dynamic mode, meaning that it is directly coupled to its own renewable energy power generation. Since the plant is not pulling energy out from the grid, it will be pushing the limits of the electrolyzers' operating envelope. This also means that on a technology perspective, we will need to install and deliver a very solid electrical backbone for the plant. This is also a challenge where we want to push the limits of the technology," adds Bentzen. Currently, ABB is working on simulations to evaluate electrolyzer and electrical-system resilience, detailing design and integrated control systems, under such dynamic conditions. The planned site for the project has access to 12 MW of existing wind-turbine power, and there are also 50 MW of newly constructed solar panels nearby. According to Skovgaard Energy, this is the first of several planned power-to-ammonia plants. ■

Mary Page Bailey

Focus on Analyzers

A self-calibrating process-development Raman system

The PTRam analyzer (photo) is a high-performance, precise, rugged and reliable Raman system featuring self-calibration and automated performance validation to ensure validity of every measurement. The system features long-lasting laser stability for consistent results, a single-channel fiber-optically coupled sample probe with user-replaceable shaft and a reliable process controller to avoid unforeseen plant shutdowns. The company's 2060 HI process analytics can be interfaced to multiple PTRam analyzers for process automation. Thanks to the variety of process communication protocols built-in with the 2060 HI (Modbus or Discrete I/O), process data can be communicated in real time to any industrial control system or directly to external devices. — *Metrohm Applikon B.V., Schiedam, the Netherlands*
www.metrohm.com

Simplified operations for this oxygen analyzer

The Servopro MonoExact DF150E (photo) has an improved digital touchscreen and icon-driven guided user interface for easier operation, combining the company's coulometric oxygen sensor with a more user-friendly package. Built around the latest innovations in software and hardware, including an updated coulometric digital oxygen sensor, the MonoExact DF150E brings users operational maintenance benefits that improve user control and reduce costs of ownership. At the heart of the MonoExact DF150E is the Hummingbird coulometric sensor, which builds on the original DF coulometric sensor's accurate trace measurements, the company says. — *Servomex, Jarvis Brook, Crowborough, U.K.*
www.servomex.com

On-site monitoring of intricate or irregular metallic samples

The Niton Apollo laser-induced breakdown spectroscopy (LIBS) analyzer (photo) is a highly portable, handheld device — based on optical emission spectroscopy — that allows users in locations like petroleum refineries and stainless-steel-production sites to measure small carbon and steel samples. Users grading and identifying complex metal-alloy structures can now benefit from the innovative optical engine and compact tapered-nose design of the Niton Apollo handheld LIBS analyzer. The device now features an enhanced laser with a reduced aperture, allowing it to measure previously challenging structures, including 1/4-in. pipes, 3/8-in. bars and larger weld wires. — *Thermo Fisher Scientific Inc., Tewksbury, Mass.*
www.thermofisher.com

Measure CO_2 in pipelines, biogas plants and landfills

The CarbonHound CO_2 gas analyzer (photo) is an accurate, cost-effective and low-maintenance method to detect and measure carbon dioxide in natural-gas pipelines, biogas plants and landfills. The online process analyzer continuously quantifies the amount of CO_2 in sample streams in real time using a non-dispersive infrared (NDIR) method of measurement. Once introduced with a sample, the IR detection element provides an output proportional to the concentration of CO_2. The signal is digitized as a 4–20-mA output, relay alarms, RS-485 or TCP/IP Ethernet to work in different process control systems. Built for use in Division 2 and Zone 2 hazardous locations, the CO_2 gas analyzer is available in an outdoor weathering packaging. The device has an accuracy and repeatability of +3% of full scale and resolution of 0.01% for readings up to 10 vol.%. — *Analytical Systems Keco (KECO), Houston*
www.liquidgasanalyzers.com

New features for this PCR thermal cycler

The new qTOWERiris (photo, p. 22) is a real-time PCR (polymerase chain reaction) thermal cycler featuring an extended wavelength range, as well as improved software and numerous new benefits. With a unique multi-color LED light source and matching

Metrohm Applikon

Servomex

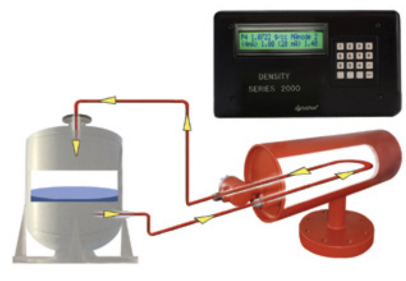
Thermo Fisher Scientific

Analytical Systems Keco (KECO)

Analytik Jena

Malvern Panalytical

Kett



Automation Products – Dynatrol Division

filter modules, the new qTOWERiris enables optimal resolution of the individual color channels and delivers reliable qPCR results with multiplexing of up to six targets. With a wavelength range from ultraviolet (UV) to near infrared (NIR), the qTOWERiris achieves unique flexibility in the real-time PCR thermal-cycler field. High-quality sample block technology ensures best thermal well-to-well uniformity and unrivaled ramping rates. The low noise emission of the qTOWERiris and its compact design make it suitable for any laboratory. — *Analytik Jena AG, Germany*
www.analytik-jena.com

Machine learning powers nanoparticle analysis

Launched in June, the NanoSight Pro nanoparticle tracking analysis (NTA) system (photo) is powered by machine learning (ML) coupled with designed-in smart features to simplify the characterization of nanomaterials. The NanoSight Pro, with upgraded NS Xplorer software, delivers advanced capabilities and improved accessibility for all users. The new instrument boasts best-in-class, ultrahigh-resolution size and concentration measurements for nanomaterials, up to three times faster than ever before. Previous limitations linked to small biological particles and other low-scatterers are overcome by NanoSight Pro, which is optimized for use with samples including exosomes, viruses, vaccines and drug-delivery systems. The instrument is powered by ML coupled with cutting-edge technology, including an upgraded temperature controller that allows stress and aggregation studies to be performed at up to 70°C. — *Malvern Panalytical Ltd., Malvern, U.K.*
www.malvernpanalytical.com

Measure moisture content with this handheld NIR analyzer

With the KJT130 handheld portable instant moisture meter (photo), the user simply points the instrument at the product and the moisture content is instantly shown on a digital display, with results accurate to 0.01% in a 0 to 100% measurement range. For ease of use, the unit is operated via user-friendly menu commands that any worker can operate. The unit, which is the size of a camcorder, is designed for frequent spot checks wherever necessary, on both stationary and moving (process line) products. Moisture measurement data may be stored in the instrument, downloaded continuously or manually recorded. — *Kett, Villa Park, Calif.*
www.kett.com

Accurate density measurement of chemicals

The CL 10-HY Density Cell and Series 2000 Density Digital Converter (photo) combine to provide online, continuous density measurement of chemicals, such as ammonium hydroxide, caustic soda, ethylene glycol, hydrochloric acid, methanol, nitric acid, oleum, phosphoric acid, sodium chloride, sodium hydroxide, sulfuric acid and many more. The Density Cell is available in a full spectrum of corrosion-resistant materials having broad temperature and pressure ratings. They are weather-tight and are approved for most hazardous-area classifications, such as CL I, Divisions 1 and 2. The Digital Density Converter has an onboard microcontroller and is preprogrammed and calibrated. Software calculates the specific gravity, percent concentration, Baume and more by utilizing the density and temperature information generated by the Density Cell. — *Automation Products, Inc. – Dynatrol Division, Houston*
www.dynatrolusa.com

Analyzers for monitoring low TOC values

The CA78 (photo, p. 23) and CA79 online total organic carbon (TOC) analyzers provide continuous and precise monitoring to ensure stable operations, regulatory compliance and high-quality products. These TOC analyzers utilize ultraviolet (UV)-oxidation and differential conductivity measurement, the most-established method for reliable TOC trace analysis in ultrapure water. The fast response time (t_{90}) of 50 s enables quick control system and personnel reaction in the event of water quality deterioration, reducing contamination, product loss and costs. The CA78 is configurable to meet various requirements in the power and semiconductor industries. For example, the standard version measures ultrapure water in semiconductor production, with conductivity

values up to 2 µS/cm. Instrument options for measurement in water with conductivity values closer to 10 µS/cm is suitable for deionized water in power plants. The CA79 TOC analyzer meets or exceeds all requirements of the U.S. and European Pharmacopoeias, enabling manufacturing activities in accordance with FDA 21 CFR Part 11. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

Endress+Hauser

A new analyzer for high-yield and brown pulp

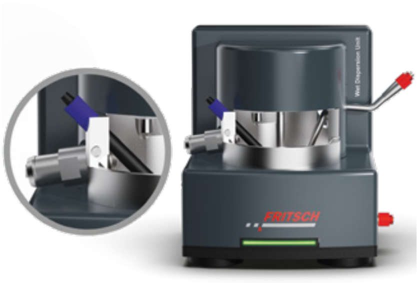
The new Brown Stock Analyzer (photo) was developed to complement this company's online pulp-quality analyzer family. The analyzer provides high analysis frequency for digester and brown-stock washing control in kraft pulping. It is said to be the most robust Kappa measurement available for high yield and brown pulp, designed to measure the coarsest pulp starting from the cooking blow line. It is the only analyzer in the market with dual sampling points for blow line Kappa, before and after refining. Accurate and frequent Kappa profile ensures superior process control and enables the mill to optimize cooking parameters, resulting in better yield and pulp quality, the company says. The analyzer uses a well-proven sampling technology to extract a pulp sample and transport it to the analysis unit, where the dissolved lignin is thoroughly washed, and pulp Kappa number analyzed by an advanced optical measurement technology. The Kappa measurement range is 9–120. — *Valmet Oyj, Espoo, Finland*
www.valmet.com

Valmet

Analyze grains with this NIR spectrometer

Said to be the most modern and accurate grain analyzer available, the Inframatic 9500 near infrared (NIR) spectrometer is reliable, robust and built to meet the requirements of grain handling operations. Designed to be used at grain receivals and grain laboratories, it can withstand harsh environments and rough handling. It analyzes a wide range of grains and oilseeds for moisture, protein, oil and many other parameters in less than 30 s. Using the optional Flour Module, the IM 9500 NIR instrument can analyze flour for moisture, protein, ash and

PerkinElmer, Analytical & Enterprise Solutions



Fritsch

more. — *PerkinElmer, Analytical & Enterprise Solutions, Shelton, Conn.*
www.perkinelmer.com

A tiny GC for fast and accurate gas analysis anywhere

Introduced at Pittcon 2023 (Philadelphia, Pa.; March 18–22), the DynamiQ-S micro gas chromatograph (GC) provides fast and accurate gas analysis for monitoring or industrial laboratory-analysis purposes. The DynamiQ-S micro GC is designed to monitor gas compositions, such as natural gas, hydrogen or biogas, in industrial processes and factory automation applications. Extremely compact, easy to handle and requiring little maintenance, the GCs enable fast and accurate online gas analysis anywhere. The integrated micro GC chips enable analysis times of less than a minute. The DynamiQ-S instrument can be programmed for continuous, unattended process monitoring, as well as manual gas analysis. — *Qmicro by Sensirion, Enschede, the Netherlands*
www.qmicro.com

Measure dispersion-liquid's pH during particle sizing

This company has developed a way to measure the pH value of the dispersion liquid almost directly in the particle-sizing measuring unit. The new pH sensor is installed as a module in the dispersion bath and connected to the laser particle sizer. It continuously measures the pH value during the measurement and automatically transfers the determined values to the software for documentation. This method covers fluctuations much more effectively than the zeta potential and offers many advantages. Monitoring the pH provides valuable information about how and when a chemically inert material, for example, reacts to alkalis, depending on the environment. If the curve is unstable and varies during measurement, the pH value helps with stabilization and interpretation. The detection of agglomeration or aggregation is also said to be much easier. — *Fritsch GmbH, Idar-Oberstein, Germany*
www.fritsch.de ■

Gerald Ondrey

Two pressure transmitters at the same measuring point

For a pharmaceutical manufacturer, this company developed a customized product to measure significantly varying pressures from a single measuring point. The solution was to use two pressure transmitters from the Pascal CV3 series, each covering different measuring ranges and both mounted on the same diaphragm seal (photo). Depending on the stage of the production process and the filling level of the tank, the system can switch from a wider measuring range of up to 4 bars to a finer measuring range of up to 400 mbars. The smaller measuring range is overload-protected and the sensor disregards the higher pressures. In order to achieve such high levels of measuring accuracy under widely fluctuating temperatures, the diaphragm seal is further equipped with a patented low-temperature-coefficient diaphragm, which compensates for any temperature-related expansion of the seal's transmission fluid. This increases measurement accuracy by up to 70%, compared to conventional sinusoidal diaphragms. — *Labom Mess- und Regeltechnik GmbH, Hude, Germany*
www.labom.com

This filter handles contaminated polymer melts

The ECO 500 (photo) is a high-performance melt filter for the filtration of heavily contaminated polymer feedstock. For chemical recycling, this technology is suitable for filtering low-viscosity polymers. The filter is self-cleaning, with a rotating, perforated drum, through which there is a continuous flow of melt from the outside to the inside. A scraper removes the contaminants that are held back on the surface and feeds them to the discharge system. This enables the filter to be used fully automatically with no disruptions over long periods without having to replace the screen. The advantages include reliable melt filtration, ultra-low melt losses, constant pressure curve, fast spreading of the contamination and short residence time of the melt in the filter. — *Maag Pump Solutions AG, Oberglatt, Switzerland*
www.maag.com

Adjust the pH with this CO_2 feed system

The new CO_2 Feed System (photo) is a safe and effective way to adjust pH and minimize risk associated with dangerous mineral acids. The 0–100% scaled flowmeter has an integral adjustment needle valve for increased accuracy. Additional benefits of the CO_2 Feed System include a NEMA 4X enclosure, illuminated on/off switch, a flow setpoint indicator, stainless-steel solenoid valve and simple push-tight tubing connectors. The CO_2 Feeder is said to be an affordable and reliable system that is simple to use and adjust. — *Blue-White Industries, Inc., Huntington Beach, Calif.*
www.blue-white.com

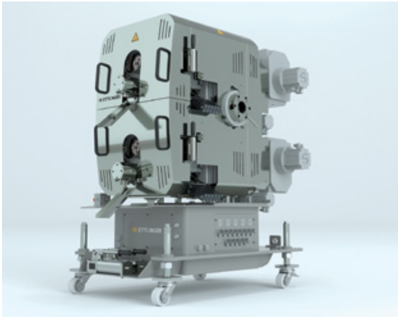
This face shield has safety goggles built in

Typically, when workers wear a face shield, they still have safety glasses on underneath. That is because most face shields have gaps on the bottom and sides that can let dangerous materials in. Conversely, Vader Combo (photo) is a face shield with the safety goggles built-in. It is one wearable piece of personal protection equipment (PPE) that does the job of two. It covers the whole face and protects the neck from foul or painful debris, sparks or liquid sprayback. Vader Combo has BK-Anti-Fog protection that lasts 15 times longer than EN 166/168 requirements for the best visibility available, says the company. Its integrated face shield offers 180-deg. peripheral vision and face coverage. — *Brass Knuckle Safety Products, Alpharetta, Ga.*
www.brassknuckleprotection.com

A digital pressure gage for use in mobile service applications

The model CPG1200 digital pressure gage (photo, p. 26) enables flexible setting of operating pressures, readjusting pressure switches and carrying out pressure monitoring, for example, leak testing during transport. The battery-operated CPG1200 has been designed for use in mobile applications. Thanks to the durable plastic case and optional protective case cap, the instrument is robust and easily withstands vibrations and shocks during use. The device covers

Labom Mess- und Regeltechnik

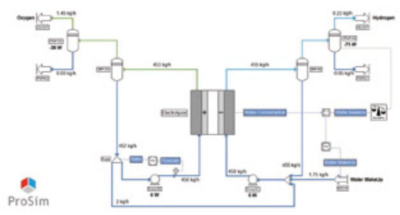


Maag Pump Solutions

Blue-White Industries

Brass Knuckle Safety Products

WIKA Alexander Wiegand



ProSim

Leuze Electronic

Endress+Hauser

Charles Ross & Son

all common ranges from –1 to 1,000 barg (–14.5 to 15,000 psig) with an accuracy of down to 0.25% of full scale. The measuring rate can be set to 1, 3, 4 or 10 measurements per second. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de

A new electrolyzer module for this simulation software

This company recently released an electrolyzer module in the new version of its ProSimPlus software (photo). By combining this module with other equipment from the ProSimPlus library, users can simulate the entire process of H_2 production via electrolysis of water and optimize the process as a whole. The new electrolyzer module has the ability to rigorously simulate an electrolysis process by offering a flexible modeling approach, depending on the data available to the user. A first approach quickly establishes the material and energy balances, taking into account possible recycling of the electrolyte solution, purges and equilibration lines, as well as determining the necessary makeup streams. A more detailed approach uses a selection of rigorous models to calculate, based on operating conditions and technological characteristics, all operating parameters: efficiency, electrical characteristics, voltage-current characteristic curves and so on. The electrolysis module allows for the representation of alkaline, proton exchange membrane and solid-oxide electrolysis cells. — *ProSim, Labège (Toulouse), France*
www.prosim.net

These towers emit clearly visible light signals

The new TL 305 series light towers (photo) provide bright and homogeneous illumination, indicating states, faults and ongoing processes clearly and visibly from a distance. The compact towers are available preconfigured with three, four or five segments. The new range of tower lights includes the TL 305 models with predefined color assignment, as well as the TL 305-IOL models with IO-Link interface. The IO-Link variants allow different operating modes and provide an extensive selection of colors. On request, the tower lights are also available with an additional acoustic signaler. The M30 thread and M12 connector make installation easy. — *Leuze Electronic, Inc., New Hudson, Mich.*
www.leuze.com

Easy-to-operate level-measuring devices

The new generation of Micropilot 80 GHz radar sensors (photo) — FMR60B, FMR62B, FMR63B, FMR66B and FMR67B — are suited for challenges when measuring points that are not easily accessible, located in dusty areas and harsh environments with extreme process temperatures and process conditions. The new generation of sensors come equipped with digital assistance operating via multiple human-machine interface (HMI) formats, including the SmartBlue application (app), making the sensors easier to use. Besides established digital-communication protocols like HART, other digital protocols, such as Profibus and Ethernet/APL, will be included in the near future. The measurement performance of the new radar chip combined with the smart Heartbeat Technology monitoring function helps to increase productivity. — *Endress+Hauser, Inc., Greenwood, Ind.*
www.us.endress.com

Multi-agitator mixing systems for specialty applications

This company has engineered a purpose-built VM-450-gallon VersaMix (photo) that features three independently driven agitators, including a two-wing center-mounted agitator with contoured bottom and Teflon scrapers to efficiently motivate viscous product throughout the mixing zone, a long helical flight agitator to produce better top-to-bottom mixing and a dual-propeller agitator for low shear, high-flow mixing. The tank of the VersaMix is fabricated from durable 304 stainless steel, designed for vacuum operation and internal pressures of up to 50 psi. For efficient discharge, a two-way, flush tank ball valve has been integrated, while a 14-in. manway provides access for ingredient additions and cleaning operations. — *Charles Ross & Son Company, Hauppauge, N.Y.*
www.mixers.com

New monitoring software for intelligent pumps

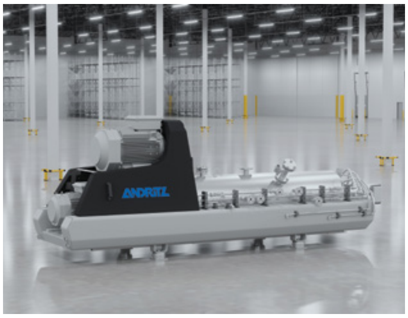
Alfa Laval AB

This company recently released new condition-monitoring software with built-in analytics. Using artificial intelligence, the new Analytics (photo) for online condition monitoring helps hygienic industries prevent unplanned downtime, extends the lifetime of valuable assets and helps reach sustainability targets. Analytics is a value-adding feature that can be added to all new and existing pump installations from this company. The solution includes a one-year subscription, including online installation, training on using the dashboard and ongoing support. Analytics collects and analyzes pump vibration data continuously and provides a clear and intuitive overview of the health condition of the equipment through a simple dashboard. — *Alfa Laval AB, Lund, Sweden*
www.alfalaval.com

Cleaning-in-place features for a bulk-material feeder

Gericke USA, Inc.

This company introduced a bulk-material feeder suitable for installation in processing lines that require cleaning-in-place (CIP) for process equipment. Developed for food, dairy, nutrition, pharmaceutical and other sanitary operations, the Feedos S-H/P CIP (photo) integrates a series of spray nozzles within the hopper and downspout in a 360-deg spray pattern to automatically remove material from inside the feeder and achieve a predetermined level of sanitization. The stainless-steel construction accommodates virtually any type of detergent, disinfectant or chemical cleaning agent, as well as hot water and steam. The CIP feeder also features a novel sealing design that replaces stuffing boxes on the drive shafts with proprietary lip seals at the feeding tool and intromitter. Connections remain tight during both operation and cleaning to prevent leakage, even in critical interfaces with moving parts. — *Gericke USA, Inc., Somerset, N.J.*
www.gerickegroup.com


Andritz

Decanter centrifuges tailored to industrial oil recovery

This company has enhanced its range of three-phase decanter centrifuges (photo) for oil recovery in the most challenging industrial applications. These three-phase decanter centrifuges are not only capable of separating liquids from solids, but also liquids with different densities, like oil and water. These proven machines have now been further developed and tailored for the recovery of high-purity oil from tainted sources, such as slop and crude oil, lake, lagoon or tank cleaning runoff and API separator sludge. Crucially for oil-and-gas applications, the decanter centrifuge range includes both ATEX Zone 1 and Zone 2 machines. This makes them suitable for use in plants where an explosive atmosphere may occur during normal operations. Machine housing seals can be supplied as gas-tight, flame- and explosion-proof versions up to P < 1.5 bars(abs) featuring a labyrinth seal system with three or more rings. Zone 1 versions have a design capacity of up to 12 m^3/h, while Zone 2 designs can achieve flowrates of up to 40 m^3/h. — *Andritz, AG, Graz, Austria*

www.andritz.com

Tsurumi America

These agitator pumps are designed for wear resistance

This company's agitator pumps (photo) are manufactured with wear-resistant components like high-chrome impellers and hard cast-iron volutes that demonstrate durability and efficiency when handling abrasive materials in applications that involve sand, grit or other debris. Agitator pumps utilize an agitator propeller that shares the same shaft as the pump's impeller. While the two spin in the same direction, the agitator blades are in the opposing orientation to those of the impeller. The agitator provides a propelling force to stir up solids near the floor, while the impeller pumps the now-suspended solids along with the fluid. They keep the mud circulating to avoid solids from settling while allowing pumping to continue without obstructions. A potted cable provides an extra layer of protection in case of accidental nicking of the exterior cable. This protection prevents moisture infiltration and, ultimately, motor failure. Using the rotation of the shaft, the oil lifter spins and flings oil throughout the seal chamber. This provides lubrication and cooling of the seal faces down to one-third of normal oil level without the need for additional power or external equipment. A built-in thermal-protection component prevents motor failure due to overloading and accidental dry-running. — *Tsurumi America Inc., Glendale Heights, Ill.*

www.tsurumipump.com


Chemline Plastics

These new check valves can be flexibly installed

The ES Series of spring check valves (photo) feature a PTFE-covered, stainless-steel spring for positive closing, as well as a new disc design for smooth, trouble-free operation. Compared to ball check valves, the ES Series requires very low liquid-head pressure to close. That means more flexibility as to where valves may be placed in a piping system. Features include high corrosion resistance, smooth trouble-free operation and easy installation and maintenance. ES Series valves are available in sizes ranging from 0.5 to 3 in. End-connection options include socket, threaded, flanged or this company's ChemFlare fitting technology. — *Chemline Plastics Ltd., Thornhill, Ont., Canada*

www.chemline.com


Cremer Speciaalmachines

Hygienic counting machines for food products

The WD Series (photo) is a new counting system designed for precise counting and dispensing of individual food products in a variety of applications where cleanliness is paramount, including poultry, meat, seafood, cheese, confectionary and bread products. WD Series machines are scalable for varying production levels. Compatible with all industrial packaging machines, highlights include a compact footprint, FDA-compliant product parts for processing both food and non-food products and streamlined tool-free disassembly. Other features include a product-detection unit with 100% reported accuracy, hinged side panels for optimal cleanability and vibratory plates for product transport and separation. — *Cremer Speciaalmachines B.V., Lisse, the Netherlands*

www.cremer.com ■

Gerald Ondrey and Mary Page Bailey

Can the Cure be as Bad as the Illness?

Henry Kister shares lessons learned from troubleshooting distillation towers

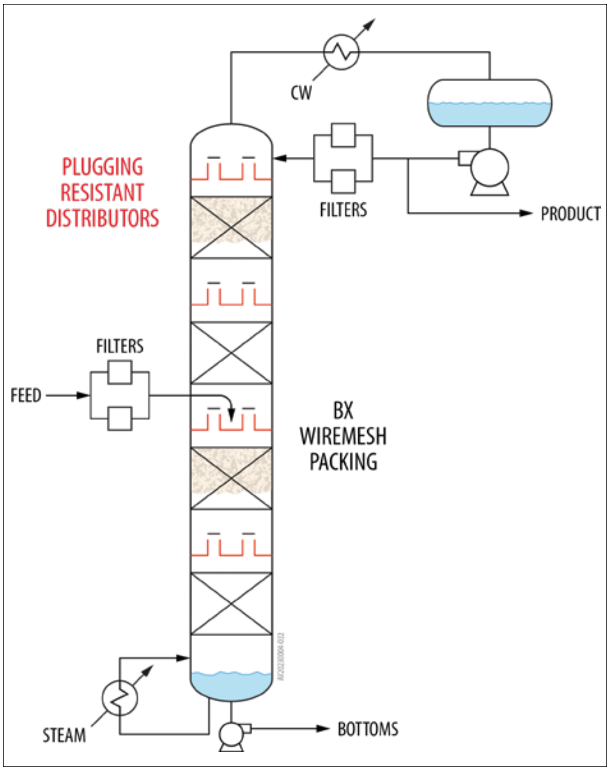


FIGURE 1. This diagram shows the tower containing wire-mesh packing that experienced poor efficiency (Diagram courtesy of H. Z. Kister)

During a course that I was presenting in Houston one year, a participant asked me the following at the end of one of the sessions: "Do you have experience with BX-type wire-gauze structured packings?"

"Sure," I responded. "Wire gauze packings are used extensively in deep-vacuum clean chemical applications. In some deep-vacuum specialty chemical finishing columns, they are the 'standard' packing used."

The course participant further inquired: "Their vendors claim they give a very good efficiency — about five stages per meter. What is your experience?"

"I have had excellent experience with them. As long as the tower and internals are clean and well-designed, the liquid loads are not too high, and the distribution is good, they usually match the vendor claims. FRI [Fractionation Research Inc., www.fri.org] tested them with excellent results that were published in the open literature. I plotted the FRI data in my Distillation Design book [*1*]," I explained.

"This is not what we are seeing in our tower. We are getting one stage per meter. Nowhere near the five stages per meter the vendor claims. The separation is terrible," he continued.

"Do you have a drawing of your distributors?" I asked. Our failure survey [*2*] showed that 80% of packed tower failures are due to poor liquid distribution. So looking at the distributors is a good starting point.

He pulled out drawings of the distributors. I took some time to review and understand them, then did a couple of sums. All looked good.

"These are good designs," I stated. "I do not see any problems with them."

He looked proudly at me. "These are our own designs. I'm glad you approve."

I was at a loss. I expected something major to be wrong with the distributors. I found nothing.

"Did you inspect the installation?" I then asked.

"You bet. Every bit of it. Everything was like it should have been," he replied.

"I give up. All looks good. I have no idea why you are getting such low efficiency."

I started packing up, but then something stopped me. I turned to him and asked, "Usually the packing vendor designs the distributors. But you said they were your design."

"Indeed," he said. "The original distributors were designed by the vendor. They did not work. So we replaced them with our designs that you liked."

"What was wrong with the vendor's distributors?" I asked.

"They used to plug all the time with solids that came in with the feed and reflux," was his response.

The exploratory questions continued: "Why didn't you install filters on these streams?"

"We had filters. They did not work."

"What was wrong with the filters?"

"They used to plug up every few hours. Our operators got tired of cleaning baskets twice per shift. So they pulled out the baskets."

At that, a moment of insight arrived. I then said, "Do you realize what happened? [Figure 1] When you removed the filter baskets, the solids traveled into the distributors and plugged them. Then you changed the distributors to a design that does not plug and allows the solids through. Do you want to guess where the solids are now?"

"You think they are in the packing?" he asked after a short hesitation.

"You got it. BX-type gauze packings are excellent filters, except that they cannot be cleaned online. Plugged packings give poor efficiency. You are lucky that at least the liquid is going through."

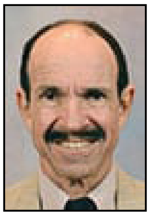
Takeaway: A cure can be just as bad as the illness. Always keep the big picture in mind. ■

Edited by Dorothy Lozowski

References

1. Kister, H. Z., "Distillation Design", McGraw-Hill, New York 1992.
2. Kister, H. Z., "What Caused Tower Malfunctions in the Last 50 Years?", *Trans. IChemE*, Vol 81, Part A, p. 5, January 2003.

Author



Henry Z. Kister is a senior fellow and the director of fractionation technology at Fluor Corp. (3 Polaris Way, Aliso Viejo, CA; Phone: 949-349-4679; Email: henry.kister@fluor.com). He has over 35 years of experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. Kister is the author of three books, the distillation equipment chapter in Perry's Handbook, and over 140 articles, and has taught the IChemE-sponsored "Practical Distillation Technology" course 550 times in 26 countries. A recipient of several awards, Kister obtained his B.E. and M.E. degrees from the University of New South Wales in Australia. He is a member of the NAE, a Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices.

Impact of Particle-Size Control on Bulk-Solids Flow Behavior

Crushing and screening of solids are essential to many solids-handling processes, but engineers must be mindful about how those actions will affect flow behavior of the bulk material

McKinnon Ray and Eric Maynard
Jenike & Johanson, Inc.

IN BRIEF

When it comes to processing bulk solids, (particle) size matters. Almost all industries rely on some sort of particle-size control within their processes, whether it is comminution (reduction of particle size by crushing, grinding or milling) or screening (separating materials based on particle size). For example, without crushing mined material, it would be impossible to extract valuable minerals and ores from the surrounding rocks. And effective screening is commonly used in the food industry to separate foreign materials and contaminants during food processing. However, crushing and screening can have unintended consequences, including causing process upsets in downstream equipment and creating potential safety issues. The good news is there are scientific approaches to evaluate these risks, and there are approaches for preventing poor process flow as a result of upstream particle-size control. This article touches on the background of comminution and screening, how both can impact processes, and how to evaluate flowability risks.

Size reduction and screening

Broadly speaking, comminution is defined as the act of reducing the average particle size of material by mechanical means. It serves as a critical process step in many industries, including mining, pharmaceutical and food industries. In general, comminution can be broken down into five methods: blasting, crushing, shredding, grinding and milling. Blasting is commonly done to reduce the size of large boulders, and of all the comminution methods, is typically used only for the largest particles. Blasting is also different from the other four methods, in that it typically occurs in the open, rather than within processing equipment. Shredding typically involves taking large, stringy materials (such as biomass, recycle waste and others) and shears the materials into smaller shreds. Grinding involves the chipping or "grinding" of a single material to create smaller particles.

Crushing can be done via three mechanisms: compression, shear and impact [*1, 2*]. Compression is typically used for hard, brittle particles and typically does not result in significant generation of fines. Shear crushing is similar to shredding, except that it is designed to handle sticky, cohesive bulk materials and powders. This method can lead to anisotropic shapes. Size reduction by impact is effective for hard, tough particles, and can lead to size reduction of 100 times smaller.

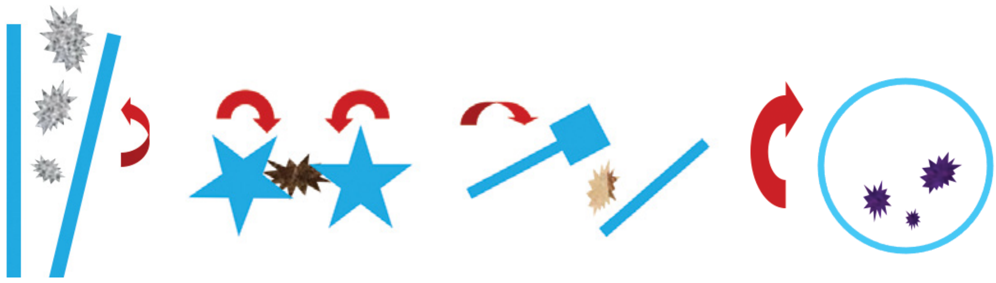


FIGURE 1: Several different particle-size reduction technologies are available for bulk solid materials

FIGURE 2. Vibratory screeners, such as the one shown here, are effective at separating over- and unders-sized material from a solid sample

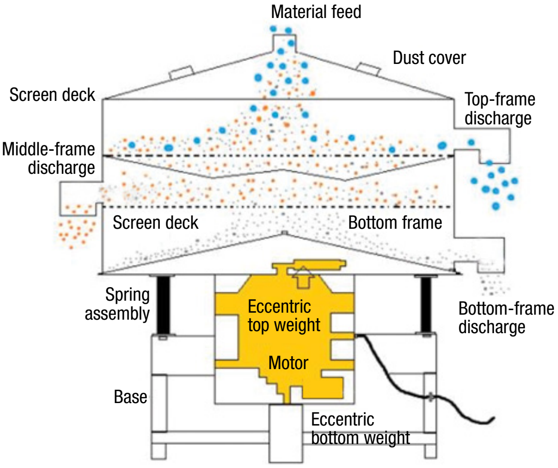


FIGURE 3. A gyratory screener, like the one shown in the schematic diagram, uses a rotational motion to separate solid materials of differing particle sizes

However, impact crushing could result in shattering of the material. Milling typically handles size reduction via a fourth mechanism: attrition. Attrition mills are commonly used as a tertiary size-reduction step, and typically take longer than the previous three mechanisms described. Examples of each of these mechanisms are illustrated in Figure 1.

Screening is another key processing step found in almost all industries. Screening is a mechanical process used in material handling to separate or classify particles into different sizes. Proper screening is critical to meet material specifications, remove foreign material, and in certain applications, can even improve flowability of the material. Similar to crushing, there are several types of screening methods, and each has its own set of pros and cons. For example, vibrating screeners (Figure 2) are great for separating oversized and undersized materials (sometimes referred to as "scalping") and generally have a higher capacity than other screeners. A single vibratory screener can have multiple decks to allow for additional material separation. Gyratory screeners (Figure 3) are like vibrating screeners, except they utilize a rotational motion to separate materials, and can be utilized for material classification. Centrifugal screening is a more aggressive method of screening that utilizes rotating paddles to allow for a high efficiency of screening in a small footprint. Tumbling screening is a gentler form of screening that combines vertical and gyratory motion in a large footprint and is common in the biomass industries (Figure 4).

Unintended effects of sizing

Comminution and screening are two crucial stages in the processing of materials across various industries. However, improper execution can have significant adverse effects on the plant operations. These effects may include reduced throughput, increased downtime, compromised product quality, and safety concerns.

To assess the impact of these effects, we can categorize them into three distinct areas: flowability, process and safety.

Flowability effects. In the design and selection of comminution and screening equipment, solids flowability considerations often take a back seat to other parameters, such as reduction efficiency, throughput, screening efficiency, capital and operating costs, as well as the equipment footprint. However, this can be a critical mistake, because comminution and screening can have drastic impacts on the flowability of the bulk solids and powders, due to increased fines generation, separation of material, changes in particle shape, and more. These changes can lead to low-flow or no-flow conditions and material quality issues. Often, these issues are found in equipment immediately downstream of the crushing and screening operations — commonly in bins, hoppers and transfer chutes. Some of the common solids-flow problems include the following:

Cohesive bridging. This is a "no-flow" condition where material forms a stable arch over bin outlets, due to the material adhering onto itself. A similar sensation, plugging, can result in complete flow stoppages in chutes (Figure 5a).

Mechanical interlocking. This is a "no-flow" condition where material forms a stable arch over bin outlets, due to the ability for coarse, aniso-

FIGURE 4. This photo shows a tumbler screener, which is common in the biomass industries

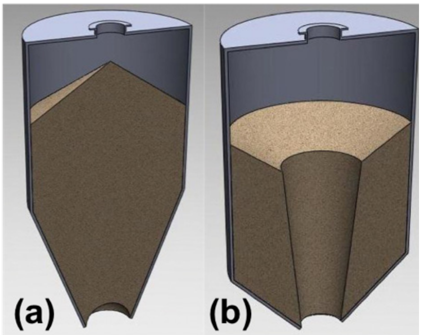


FIGURE 5. Cohesive bridging (a) and ratholing (b) are two common no-flow conditions that can occur downstream of screening equipment

FIGURE 6. Fine material can be a problem if it builds up on the inside of bins and chutes

tropic materials to interlock and form strong physical bridges.

Ratholing. This is a "no-flow" condition where a stable, open channel forms above the outlet and stagnant material outside of the channel does not empty (Figure 5b).

Buildup. This is a condition where material is allowed to build up within bins and chutes (Figure 6).

Limited discharge rate. This is a "not-enough-flow" condition when interactions between fine material and air restrict the solids discharge rate.

Flooding. This is a condition where-interactions between fine material and air can cause the solid material to behave like a liquid, resulting in the material overwhelming downstream equipment (Figure 7).

Segregation. This is a condition in which the material can segregate itself based on a number of different mechanisms. In comminution and screening applications, this can lead to reduced efficiency (Figure 8).

Caking. This is a condition in which stagnant material may agglomerate into lumps, potentially causing flow stoppages. The risk of this is increased when handling hygroscopic materials (Figure 9).

Dust generation. This is a mechanism by which additional release of fine particles can lead to overloading of dust-collection equipment.

The effects of comminution and screening are often determined by the quantity and distribution of the particles' size following the sizing step. If a crushing operation results in a wider particle-size distribution, segregation of particles can occur, which can influence product quality and flowability. On the flip side, if a crushing operation leads to a narrow particle-size distribution, mechanical interlocking of similar sized particles can occur, which can result in flow obstructions, as well as screen blinding.

An example from the cement industry can help illustrate the concepts. Limestone is a critical ingredient in cement manufacturing and typically makes up approximately 80% of cement chemical composition. Blasting is conducted in the limestone quarry to extract limestone. Following blasting, large limestone rock is fed into a primary crushing operation, often a gyratory crusher. Following primary crushing, limestone is often transported via belt conveyor to a primary stockpile. Because the limestone has undergone significant size reduction, a large portion of the limestone is now fine. Fine limestone can be more cohesive than the original limestone rock, and thus, more prone to bridging, which can limit flowrate out of the stockpile. Ratholing can also occur within these stockpiles, and this can effectively reduce the live capacity of the stockpile significantly (often by up to 90%).

Bridging and ratholing are not the only negative side effects that can occur in this example. Segregation of fine and coarse limestone can occur, which will not only intensify cohesive bridging and ratholing, but can lead to separate "slugs" of fine and coarse limestone downstream. If a slug of fine material is discharged from the stockpile, dusting can occur, leading to material spillage, overloading of dust collection equipment, and inefficient use of crushing equipment, which can reduce equipment life. Likewise, if a slug of coarse limestone is sent downstream, it can mechanically interlock at hopper outlets, creating "no-flow" conditions, reducing crushing efficiency and blinding screening equipment.

Process effects. Negative flowability side effects are not the only concern of improper particle-size reduction. Improper crushing can have a direct impact on product quality, and can lead to either reprocessing or increased scrap product. Crushing can also reduce material integrity, leading to "weaker" material, resulting in less stable particles. Processes that include chemical reactions can be negatively impacted, because particle size can have a direct impact on reaction time and efficiency. The same can be said for drying processes, in which unsuccessful crushing can lead to either over- or underdried material. Inefficient screening has a direct impact on product quality and could allow foreign material to enter the material stream.

Safety effects. As anyone in involved in manufacturing industries will tell you, safety is the number priority. Crushing and screening can have massive safety impacts. Obviously, machine entanglement is a major concern in the design of crushing and screening applications. But the potential safety hazards do not stop there. For materials that are explo-

FIGURE 7. Solids flooding occur when fine material interacts with air in such a way that the solids behave as a liquid

FIGURE 8. Segregation of fine and coarse particles can occur in gyratory screener

sive, dust explosivity risks can be drastically increased if crushing leads to increased dust generation. According to a study conducted by the U.S. Chemical Safety Board (CSB; Washington, D.C.; www.csb.gov), dust explosions pose a significant safety hazard, resulting in 718 injuries and 119 fatalities in the U.S. between 1980 and 2005 [*3*]. Additionally, increased dust generation can increase human exposure to chemical and toxic respiratory hazards.

Evaluating risks

Fortunately, flowability, process and safety risks can and should be identified before selecting comminution and screening equipment. Assessing these risks can be broken down into three steps:

1. Evaluate the material's physical, chemical and flow properties
2. Conduct a flowability and size-reduction review
3. Perform preliminary safety assessments

Material characterization is paramount not only in selecting size-reduction and screening equipment, but also in the design of all solids handling equipment. Just as it is imperative that a car mechanic run diagnostics tests to understand how a car's engine and transmission work together before beginning repair work, it is critical to fully evaluate the material being crushed or screened before selecting comminution and screening equipment. Unlike liquids and gases, you won't find critical solids-flow property data in textbooks or manuals. Rather, flow property testing must be performed to establish design criteria. Common flow properties evaluated include the following:

- Cohesive strength – Used to determine hopper outlet sizing to prevent cohesive arches and ratholes from forming, as well as plugging, caking potential and buildup
- Wall friction – Used to evaluate solids flow along the inside surfaces of the hoppers, transfer chutes, and screens. Commonly used to determine critical hopper angles to avoid funnel flow pattern
- Compressibility – Used to establish the relationship between consolidating pressure and bulk density

Flow properties are not the only characteristics needed before selecting comminution, screening and other solids-handling equipment. As discussed earlier, most powders are explosive, and if conditions align,

FIGURE 9. The material shown here is fine wheat that is exhibiting caking behavior

could create dust fires, deflagrations and explosions. Combustible-dust testing is critical in evaluating whether a material can form a combustible dust at the necessary concentration, and if so, how severe the explosion could be. Further, toxicity hazards should be established in this phase.

Once the material is properly characterized, comminution and screening equipment should be evaluated. Going back once again to the earlier cement-industry example, consider a very wet, cohesive limestone. Recall from that example that gyratory crushers are often used in primary crushing. This is highly effective at reducing large limestone rock, and could lead to 6:1 size reduction within the rock. However, if the limestone has a significant clay concentration, plugging of the gyratory crusher can occur, severely limiting throughput. Perhaps in this application, it makes more sense to utilize a shear crusher, which is better suited at handling sticky, cohesive materials. Likewise, the transfer chute following the crusher must be designed to prevent buildup, plugging and dusting of fine limestone particles. The same concept applies to all equipment downstream, including screeners, silos, dust collectors and feeders. Conducting a proper "flowability" review of the entire system before it goes online can reduce downtime, improve product quality, and result in significant operating cost savings.

Once equipment is selected and process flow diagrams begin to take shape, the most important step takes place. Designing safe processes is paramount, and final safety assessments should be performed before commissioning any comminution or screening equipment. In fact, the Occupational Safety and Health Administration (OSHA; Washington, D.C.; www.osha.gov) recommends beginning with a process hazards analysis (PHA) to identify, evaluate and develop control schemes for highly hazardous materials [*4*]. Likewise, a dust hazards analysis (DHA) should be performed to evaluate potential fire, deflagration and explosion hazards, before the equipment goes online. In fact, the National Fire Protection Association (NFPA) requires DHAs for many industries, including chemicals, food processing and woodworking [*5*]. PHAs and DHAs should be performed by qualified professionals who have knowledge in industrial safety and specific hazards associated with the materials being handled.

Concluding remarks

In most industries that handle solids, comminution and screening operations are crucial. There are various methods and technologies available for comminution and choosing the appropriate one can significantly affect the efficiency of energy usage, product quality, and the equipment lifespan. Similarly, screening methods can also have many of the same significant impacts. Both operations may lead to unintended consequences that can increase the risk of flow disruptions, downtime and safety hazards. However, by assessing the physical, chemical and flow properties of the materials, conducting a thorough flow processing review, and performing PHAs and DHAs when necessary, it is possible to mitigate these risks before implementing comminution and screening processes and before purchasing equipment. Following these steps will ensure that new operations will function correctly and safely right from the start. ■

Edited by Scott Jenkins

Editor's note: all photos and diagrams in this article appear courtesy of Jenike & Johanson

References

1. Maynard, Eric. Fundamentals of Crusher Selection. *World Cement*, March 2010.
2. Maynard, E. (Presenter), and Cronin, K. (Moderator). Break it Down! How to Effectively Choose Size Reduction Equipment [Webinar]. Powder & Bulk Solids by Informa Markets, February 15, 2023.
3. Combustible dust safety. Chemical Safety Board (CSB). www.csb.gov/recommendations/mostwanted/combustibledust/
4. Occupational Safety and Health Administration. Process safety management: Hazards. Retrieved May 3, 2023, from www.osha.gov/process-safety-management/hazards
5. NFPA 652, "Standard for the Fundamentals of Combustible Dust", 2016 ed.

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Materials of Construction for the CPI

The proper selection of materials of construction is crucial. The example presented here shows how to use standards to help narrow down the options

William M. Huitt
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IN BRIEF

ASTM STANDARDS

ASTM AND ASME

DEVELOPING A MATERIAL SPECIFICATION

FLUID SERVICE COMPATIBILITY

PROJECT DESIGN BASIS

MATERIAL COSTS

Since the late 1800s, a steady body of pressure technology codes and standards have been under development (see box on p. 36) providing engineers with standardized methods to safely design and fabricate pressure vessels and other pressurized process equipment used in the chemical process industries (CPI). This article gives an overview of the relevant standards, and presents an example of how they can be used to narrow down the selection of suitable materials of construction (MoC).

ASTM standards

Operating for 125 years, ASTM International (ASTM; West Conshohocken, Pa.; www.astm.org) has come a long way since standardizing on the material and testing of railroad track steel. It currently publishes and maintains 12,500 standards globally in over 140 participating countries with the help of more than 30,000 volunteer and staff members. This is an organization that we depend on for determining and evaluating a material's chemistry, its strength, its testing, and manufacturing requirements. ASTM is also involved in developing testing methodologies and procedures.

In all, ASTM publishes, among other things, six different types of standards that include the following:

Test Method Standards: A set of procedures that provide instruction, guidelines, and parameters necessary to acquire and analyze sample evidence of fluids and materials.

Practice Method Standards: Are instructions on the recommended approach to achieving a deliverable in a standardized fashion. Such examples include F748 Standard Practice for Selecting Generic Biological Test Methods for Materials and Devices and E1816 Standard Practice for Measuring thickness by Pulse-Echo Electromagnetic Acoustic Transducer (EMAT) Methods.

Specification Standards: Are standards that specify what the intended use is for a specific material, the material's chemical composition parameters, mechanical properties, the manufacturing process, testing requirements, and all other use and manufacturing requirements pertaining to a specific material and its various product forms

Classification Standards: Provide guidance and requirements for the process of assigning the various materials, services, or systems into their proper category. These requirements may relate to the origin, the physical properties, or the chemical properties of the product itself.

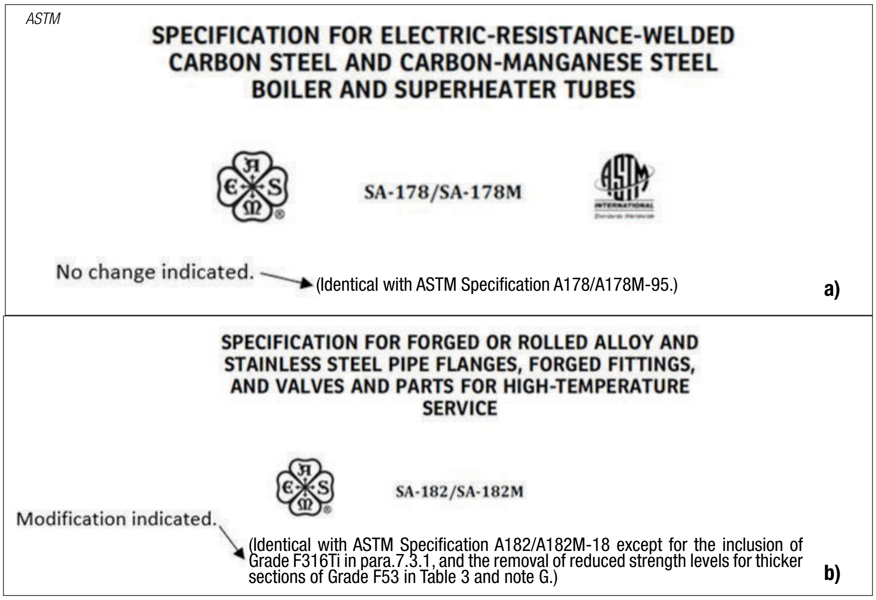
Guide Standards: Are collections of information or series of options that do not recommend specific courses of action. They generally inform people of the knowledge and approaches being taken in given subject areas.

Terminology Standards: Provide definitions of terms and explanations of symbols, abbreviations, and acronyms used throughout ASTM.

What we can pull from the above list, relative to this discussion, is item three, Specification Standards, which covers the following seven categories:

- Class A – Ferrous iron and steel metals and products (prefix A)
- Class B – Nonferrous metals and products (prefix B)
- Class C – Ceramic, concrete and masonry materials
- Class D – Miscellaneous materials
- Class E – Miscellaneous subjects
- Class F – Materials for specific applications
- Class G – Corrosion, deterioration, weathering, and degradation of materials and products

We will further narrow our focus down to the above Class A – Ferrous iron and steel metals and products. This is where most of the piping and equipment material for the CPI are found. Nonferrous materials are frequently used as well, but that would be too much to cover here. ASTM includes plastics under the above Class D – Miscellaneous materials. So, for nonmetallic (NM) material, refer to the relatively new ASME NM standards first published in 2018 by the American Society of Mechanical Engineers (ASME; New York, N.Y.; www.asme.org). They include the following:


ASTM

SPECIFICATION FOR ELECTRIC-RESISTANCE-WELDED CARBON STEEL AND CARBON-MANGANESE STEEL BOILER AND SUPERHEATER TUBES

SA-178/SA-178M

No change indicated. (Identical with ASTM Specification A178/A178M-95.) a)

SPECIFICATION FOR FORGED OR ROLLED ALLOY AND STAINLESS STEEL PIPE FLANGES, FORGED FITTINGS, AND VALVES AND PARTS FOR HIGH-TEMPERATURE SERVICE

SA-182/SA-182M

Modification indicated. (Identical with ASTM Specification A182/A182M-18 except for the inclusion of Grade F316Ti in para.7.3.1, and the removal of reduced strength levels for thicker sections of Grade F53 in Table 3 and note G.) b)

FIGURE 1. Shown here are the covers for SA-178/SA-178M (a), which indicates no change from the ASTM version, and (b) for SA-182/SA-182M, which indicates a change from the ASTM version

- ASME NM-1 – Thermoplastic Piping Systems
- ASME NM-2 – Glass Fiber Reinforced Thermosetting Resin Piping Systems
- ASME NM-3-1 – Nonmetallic Materials Part 1 Thermoplastic Materials Specs
- ASME NM-3-2 – Nonmetallic Materials Part 2 Thermoset Plastic Materials Specs
- ASME NM-3-3 – Nonmetallic Materials Part 3 Properties

ASTM and ASME

In the process of selecting material for pressurized equipment, there may be some confusion surrounding the issue of specification numbers between ASTM and those of ASME having a different prefix. What I refer to is the prefix A attached to ASTM specification numbers and the same ASME material specification numbers in the ASME Boiler and Pressure Vessel Code (BPVC) Section IIA for Ferrous Metals having an SA prefix. Section IIB for Nonferrous Material will have SB as the prefix. Within the BPVC are listed materials that comply with applications used in the manufacture of boilers and pressure vessels. These listed materials are contained in the ASME BPVC Sections II Materials, as follows:

- Part A — Ferrous Material Specifications (Beginning of SA-450)
- Part B — Nonferrous Material Specifications
- Part C — Specifications for Welding Rods, Electrodes and Filler Metals
- Part D — Properties (Customary)
- Part D — Properties (Metric)

ASTM, in standardizing a material specification, will provide all of the essential elements based on a material's chemistry, manufacturing process, intended use, testing and examination requirements. And in many cases, a specification will be broken down into multiple grades and classifications, plus various supplemental qualifications.

ASME BPVC draws from the ASTM pool of material specifications and then qualifies, or vets those specifications through testing and theoretical analysis to qualify the material for use under the requirements of the BPVC. In doing so, the vetted material specification will retain the same ASTM number, but ASME will add an "S" to the ASTM prefix to designate the adopted ASTM specification as an ASME qualified specification. For example, ASTM A182/A182M would become ASME SA182/SA182M under the ASME BPVC. In many cases the adoption of an ASTM material specification will remain the same, without change. But in some cases, the ASME material specification will be modified from its original ASTM material specification to meet the requirements of the ASME BPVC. In the ASME version of a material specification, it will be explained on the cover page of a material specification as to whether or not a material specification was altered in any way, as shown in Figures 1a and 1b.

Two things you may notice, besides the indicated note and the different specification numbers, is that Figure 1a has the ASTM logo included on the specification cover page in which there is no change to the specification. This specification has been adopted by ASME as written by ASTM. And it states so on the cover sheet in posting that it is, "Identical with ASTM Specification A178/A178M-95."

In Figure 1b, the ASTM logo is not included on the cover page, due to the fact that ASME has determined that the specification required modification in order to meet the requirements of the BPVC. And it states so on the cover sheet in posting that it is, "Identical with ASTM Specification A182/A182M-18 except for the inclusion of Grade F316Ti in paragraph 7.3.1, and the removal of reduced strength levels for thicker sections of Grade F53 in Table 3 and note G."

With regard to piping, the materials listed for use in piping applications are listed in Appendix A-1 and A-1M of the ASME B31.3 Process Piping Code. In the listing of acceptable materials under the piping code, you will notice that the ASTM material specification number is retained, as in ASTM A182/A182M. The materials listed in B31.3 have been vetted by that committee and approved for use as pressure-

TABLE 1. LEGEND OF CORROSION RATES

Symbol	Corrosion rate, in./yr	Corrosion rate, mm/yr
A	<0.002	<0.05
B	<0.020	<0.50
C	<0.050	<1.27
NR	>0.050 in./yr or explosive, not recommended	

A BRIEF HISTORY OF STANDARDS

In the late 1800s, boiler explosions were occurring at an alarming rate due to the fact that manufactures of pressure containment vessels for steam pressure was an unfettered and crude process, at best. The application of steam pressure as a power source was ahead of our ability to manufacture vessels that could safely contain that pressure. The industry was ruled by over-powering industrialists at the time who did not want, nor did they allow any bureaucrat or engineer to tell them how to manufacture their product. There were no organizations — government or otherwise — that could step in and put a stop to the disastrous and unregulated methods of manufacturing pressure vessels that were being perpetrated on industry and the public.

"The Grover Shoe Co. incident [in which 58 people were killed, and approximately 150 people injured in the town of Brockton, Mass.] created sufficient incentive for the state of Massachusetts to do something about the lack of standardization for pressurized equipment used in that state, specifically as it related to boilers. But it was not until the following year when another boiler explosion, in yet another shoe factory, located this time in Lynn, Mass., finally shook the Massachusetts government out of its bureaucratic complacency and into immediate action. It prompted them to initiate and pass 'An Act Relating to the Operation and Inspection of Steam Boilers' in 1909. This Act would become a preeminent early step in promoting additional interest and consensus of the work the ASME had been involved in and working on since 1884, that of standardizing on the design and materials of construction used in the fabrication of pressure vessels" (quoted from the author's article, "Piping Codes: What the CPI Engineer Should Know," *Chem. Eng.*, October 2016, pp. 42–53).

The ASME Boiler and Pressure Vessel code (BPVC), which, after much turmoil and initial dissention among its membership, had finally achieved consensus — thanks sadly to too many disasters, such as those in Brockton and Lynn — and was published in 1914, but not printed and released until 1915.

On the heels of the work that ASME was doing, a group of scientists and engineers in 1898 formed the American Society for Testing Materials (ASTM). This was in response to steel railroad tracks all too frequently failing under the stress of operation. In 1961, the name was changed to the American Society for Testing and Materials (ASTM). In 2001, its name was changed once again to its current name of ASTM International.

Membership between ASME and ASTM International overlaps in many cases in which some people hold membership in both organizations. Such dual memberships of these organizations provide much-needed dialog and harmonization between the two groups. Effectively marrying the design and fabrication (ASME) with material of construction (ASTM) in such a way that the results are a seamless relationship that benefits the two organizations and the industry at large. ❐

containing piping material without change to the ASTM specifications. Any material not listed in B31.3 for use in pressure-containing fluid services can be submitted to the committee for approval in accordance with ASME B31.3, paragraph 323.1.2, as follows:

***323.1.2 Unlisted Materials**. Unlisted materials may be used provided they conform to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meet the requirements of this Code. See also ASME BPVC, Section II, Part D, Appendix 5. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Code or a more conservative basis.*

By stating the following in paragraph 323.1.2 above: "…a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control…" it is referring to internationally accredited material specification organizations. such as the following:

- ASTM International – American Society for Testing and Materials, International
- AISI – The American Iron and Steel Institute
- BSI Group – British Standards Institution
- CSA Group – Canadian Standards Association
- DGN – Dirección General de Normas
- DIN – Deutsches Institut für Normung
- GB – Guobiao
- ISO – International Organization for Standardization
- JISC – Japanese Industrial Standards Committee

TABLE 2. EXPECTED RATE OF CORROSION (CS)			
Fluid Service	MoC	Compatibility at Fluid Composition and Temperature	
NaOH 50%	Carbon steel (A53/A53M)	1	A/NR 50-100% at 70ºF
		2	NR 50-100% at 100-150ºF
		3	C/NR 50-100% at 150-180ºF
		4	NR 25-100% at 190-800ºF
		5	C/NR 30-50% at 180-200ºF
		6	AB up to 50% to 150ºF
		7	AB up to 22% to 220ºF
		8	A to 2% to 205ºF

Working across international boundaries with specifications published by organizations like those listed above, can be both a little daunting, confusing, and a little difficult at times. There is no intended direct correlation between the various material specifications and standards published around the world. But in these many material specifications, the chemistry is typically not specified in exacting amounts. The chemical compositions are instead given as a weight percentage with a maximum value or a value range, not a specific target amount. What this does is provide an environment or situation in which the chemistry in a specification from one country can overlap that of another country. But the practicality of an exact chemistry match occurring, in which all of the chemistry constituents between two specifications from two different countries will match up, is not going to happen. Transposing specifications from those published by two different countries requires someone very familiar with the nuanced effect that the various alloys have on the chemistry that make up a steel. This also applies to the melting temperature, the cooling process, and post treatment of the metal manufacturing requirements. Such determination in transposing material specifications published by one organization to that of another requires an expertise in metallurgy.

Developing MoC specifications

With the wide and varied selection of steels that are available in the marketplace, how do you go about determining which material to use for a specific application and fluid service? There are many more variables that go into determining a proper material for any number of specific process applications than are discussed here. But what we can do is set the stage for a methodology by providing examples of things to be aware of. And I say that because it is not merely a matter of matching up a metallic material to a process fluid service. There are outlier conditions that may also need to be considered. And you will see why as we move through this discussion.

Finding a compatible material to contain a process fluid service for piping or equipment is a paring down process of elimination. The following outlines key points in a process that helps to arrive at a suitable MoC:

1. Find general materials that are reasonable and compatible candidates for the applicable process fluid service chemistry.
2. From the materials selected in Step 1, further select materials that can withstand the expected design pressure and temperature conditions.
3. From the materials selected in Step 2, we now have to consider what I referred to earlier as possible "outlier conditions."
4. Assess the cost.

For Step 1 indicated above, what I mean by "reasonable" is to disregard, right at the start, the more costly materials, such as the higher alloy materials. Begin with the basic carbon steels such as an ASTM A53 or A106 if they are a good place to start from. The process might then lead you to a possible stainless steel, nickel alloy, pipe lined with nonmetallic material, or nonmetallic material. So, in order to work through the above four steps in some meaningful way, we will set up a sample fluid service to make some necessary points in our evaluation. The sample fluid service will consist of the following essential elements:

- Fluid: 50% NaOH
- Operating temperature: 70°F (21°C)
- Design Temperature: 95°F (35°C)
- Operating pressure: 80 psig (5.5 barg)
- Design pressure: 110 psig (7.6 barg)

Fluid service compatibility

The first step is to find compatible material types for a specific process fluid service. This will immediately pare down the overly broad field of possible candidate materials to a smaller select group of materials. To do this I would suggest referring to sources that have compiled test results data on the compatibility of various steel materials (as well as other metals) with that of various fluids.

Such sources will provide the rate of corrosion a material will sustain while in contact with a specific fluid at various temperatures. They typically present the results by indicating, in various ways, that the material is acceptable, nominally acceptable, poor, or not recommended for application with the specified fluid at a specified temperature.

In selecting our material in this regard, we need parameters upon which we will make our decision in selecting a suitable material. Those parameters include the degree of corrosion rate we can accept for the intended service application. So before starting through the selection process I will define and explain those parameters.

Project design basis

To begin with, the design basis of a project is a procedure that lays out the essential elements of designing and constructing a process facility. In it, along with many other

foundational metrics for a project, will be a durational period for which the process facility is intended to operate and the basis from which operational cycles are calculated and the length of time in service for materials is established. Knowing that length of time permits us to determine, once we know the corrosion rate of a material, how much wall thickness material loss will possibly occur over the life of a piping system or a pressure vessel. This gives the wall thickness that will be required in order to allow for the loss of material through corrosion over the expected facility life and still have sufficient strength in the remaining wall thickness to retain the specified internal pressure at the end of a facility's lifecycle.

In essence, what needs to happen in developing specifications for a project, or for a corporate library of procedures, specifications and standards, is to give some forethought with regard to corrosion allowance (CA). This is an essential element in the process of selecting material. But in building a material specification, it should be created in a way in which any number of conditions (fluid services versus MoC) can be met. This means that an attempt should be made in developing a specification to allow it to meet the needs of multiple fluid services, if possible.

In this generalization we will look at corrosion rates for carbon and non-alloy steels for non-aggressive fluids as well as stainless steels and other alloys selected for use against aggressive fluids, as follows:

Example 1.

a. Corrosion rate rule of thumb for non-aggressive fluids (that is, cooling tower water, chilled water, and so on) in carbon-steel pipe is to allow a corrosion rate of 1 mil/yr (0.001 in./yr) of general corrosion. This is a nominal value to allow for the rate of corrosion for this general type of material. If the rate of corrosion exceeds this to a point in which the pipe wall schedule has to be increased, then you might need to look at an alloy steel.

b. A corrosion rate for stainless steels and higher alloys selected for use against aggressive fluids (that is, sulfuric acid, NaOH, hydrofluoric acid and so on) is typically assessed at 0.000 in.

c. Assume a design basis of a 20-year facility life cycle.

d. The amount of corrosion allotted for carbon-steel material, based on 1 mil/yr over the 20-year life of the facility would be 20 x 0.001 in. = 0.020 in. (total expected corrosion over the life of the facility)

e. The amount of corrosion allotted for alloy-steel material, over the 20-year life of the facility would be 0.000 in., but the specified CA would, in some cases, be 0.030 in. to include a margin of safety.

f. Corrosion seldom occurs evenly throughout a system. It would therefore be wise for maintenance within the operating facility to periodically check for localized corrosion at specific locations, such as impingement areas, possible cavitation areas, downstream from pressure-reducing valves (PRVs), and so on.

Based on the suggested corrosion rate expressed in item d above, the CA typically applied to carbon steel would be 0.050 in. And based on the suggested corrosion rate expressed in item e above, the CA typically applied to steel alloys is 0.00 in. to 0.032 in. The reason behind those applied CA values will be made apparent after the following example listing the essential elements of a selected material:

Example 2.

a. 6 in. NPS A53 Gr B ERW carbon-steel pipe

b. Sch. 40 has a wall thickness = 0.280 in.

c. Deduct manufacturers tolerance of 12.5% from specified wall thickness (the manufacturing tolerance is specific to each material specification)

1) Manufacturers tolerance 0.125 × 0.280 = 0.035 in.

d. Assigned CA value is deducted from specified wall thickness:

1) CA typically used for carbon steels = 0.050 in.

e. Total deductions from wall thickness = 0.035 in. + 0.050 = 0.085 in.

f. 0.280 in. wall thickness. – 0.085 in. total deductions = 0.195 in. remaining wall thickness at the end-of-life cycle

Projecting a remaining wall thickness of 0.195 in. at the end of the calculated life span of a facility the burst pressure, based on that remaining wall thickness, would be calculated using Equation (1):

$$B = \frac{2 \times T \times S}{D} \tag{1}$$

Where:
B = Burst pressure, psi
D = Pipe O.D., in.
S = Minimum ultimate tensile strength, psi
T = Pipe wall thickness,

For this exampe, Equation (1) gives the following:

B = (2 × 0.195 × 60,000)/6.235 = 23,400/6.235 =
3,753 psi (≈ 3,750 psi)

With this information, we can then calculate maximum allowable pressure (MAWP) for the piping based on its lifecycle of 20 years. MAWP is a term used in the ASME BPVC and is not used in the piping code. But using it for piping in this case will help the narrative. Using a safety factor of 4, and a bursting pressure of, say, 3.700 psi, the MAWP is 3,750/4 = 937.5, or approximately 930 psi (refer to ASME Sect. VIII, Div 1, para. UG-101, (m), Bursting Test Pressure (with the exception that the equation used above to calculate the safety factor does not represent the full equation found in paragraph (m), (refer to Equations (2) and (3)):

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu\, ave}} \tag{2}$$

or

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu r}} \tag{3}$$

Where:
E = efficiency of welded joint, if used (see Table UW-12)
P = Maximum allowable pressure, psi
S_μ = specified minimum tensile

TABLE 3. EXPECTED RATE OF CORROSION (SS)

Fluid Service	MoC	Compatibility at Fluid Composition and Temperature	
NaOH 50%	Carbon steel (A53/A53M)	1	A to 100% to 125ºF
		2	A 100% to 250ºF
		3	BC 100% 250¬–600ºF
		4	A 100% 600–650ºF
		5	NR 90–100% 750–800ºF
		6	A to 80% to 175ºF
		7	B/NR 70–90% 180–300ºF
		8	B 60–99% 300–500ºF
		9	A to 60% to 212ºF
		10	AB 40–70% 212–250ºF
		11	A to 30% to 250ºF
		12	NR 10–60% to 255–345ºF

strength at room temperature

$S_{\mu\ avg}$ = average actual tensile strength of test specimens at room temperature

$S_{\mu r}$ = maximum tensile strength of range of specification at room temp.

Having posited an approach above in determining the strength of our piping system at the end of its lifecycle, we will now revisit the manner in which the assigned CA was determined for both the carbon-steel materials and the alloy-steel materials.

Item “a” under Example 1 above, points out that the corrosion rate allotted for carbon steel material in this discussion is based on 1 mil/yr. It then goes on in item “d,” under Example 1, to extrapolate that corrosion rate out over a 20-year facility life span as in: 20 × 0.001 in. = 0.020 in. The assumption here is to conclude that, if you need to assign a higher corrosion rate than 0.001 in./yr, then you may need to go to an acceptable steel alloy, nonmetallic material, or pipe lined with nonmetallic material. But how do you know how much of a corrosion rate to assign to a particular fluid service as compared to a specific MoC?

As mentioned earlier there are published resources available that can provide such data. In one such publication, you will find the legend in Table 1 to indicate rates of corrosion.

The symbols in Table 1 will indicate in Tables 2 and 3 the expected corrosion rate per year based on our fluid service and the data from the sources mentioned earlier, namely, fluid 50% NaOH, 70°F operating temperature, 95°F design temperature, 80 psig operating pressure and 110 psig design pressure.

In checking the published data for 50% NaOH with a design temperature of 95°F and a MoC of carbon steel, we find the expected rate of corrosion information given in Table 2. Refering to Table 2, we see that the 50% NaOH solution at the 95°F design temperature in carbon steel, line item number 6 within the table would indicate a possible corrosion rate of between 0.002 to 0.020 in./yr. Following the old adage that you should, “plan for the worse and hope for the best,” we will assume a corrosion rate of 0.020 in./yr, which gives us an accumulated corrosion loss of 0.400 in. at the end of the 20-year facility lifecycle. With that rate of corrosion, 0.020 in./yr, it would surpass both the manufacturing allowance (0.035 in.) and the specified corrosion allowance within 5 years, which is not even close to the desired 20-year lifecycle.

I mentioned earlier that, “There are outlier conditions that may also have to be considered.” And at this point I will include one. If you are heat-tracing a piping system containing 50% NaOH in which the heat tracing is set at somewhere between 250°F and 455°F, the heat tracing will create a high-temperature zone on the piping. In referring to Table 2, we can see that once the pipe-wall temperature exceeds 200°F with piping that contains 50% NaOH, it has a detrimental effect on the piping material. Depending on how much in excess of the 200°F the heat tracing is operating at, pits will begin to form. These corrosion pits will penetrate the pipe wall within a matter of a week or two and leak the NaOH out to the environment. This is intended to point out the fact that there could be extenuating circumstances to consider beyond the rudimentary fluid compatibility at design temperature.

The first consideration of carbon steel was based on cost and the possibility that it would be acceptable, which in this case, it does not. If we go to the next higher cost value, we might look at a 304 stainless steel. It is one of the less expensive steel alloys that might very well do the job. In looking at Table 3, 304 stainless steel is very compatible with the 50% NaOH fluid service at a design temperature of 95°F. And the stainless material remains compatible with 50% NaOH at elevated temperatures up to 212°F.

In this case, a schedule 10S 304 stainless steel would be a good selection, from both a cost and compatibility standpoint for the 50% NaOH fluid service. But there are other cost-wise options as well, such as nonmetallic material. But the point being made here is in the selection process itself. And in selecting a compatible MoC ensure that you have identified any outlier concerns, like the heat tracing in this case, or make certain that there are no additional concerns. A conversation with the chemical engineer would help along those lines. Such a misstep could have catastrophic implications weeks or even years down the road — a misstep that could be lethal.

In addition to the outlier concern regarding heat tracing of an otherwise ambient fluid temperature described in the above discussion, ASME B31.3 Appendix F, paragraph F323.1 General Considerations, points out a number of other concerns that might be considered when selecting piping material, as follows:

- The possibility of exposure of

the piping to fire and the melting point, degradation temperature, loss of strength at elevated temperature, and combustibility of the piping material under such exposure

- The susceptibility to brittle failure or failure from thermal shock of the piping material when exposed to fire or to fire-fighting measures, and possible hazards from fragmentation of the material in the event of failure
- The ability of thermal insulation to protect piping against failure under fire exposure (for example, its stability,fire resistance, and ability to remain in place during a fire)
- The susceptibility of the piping material to crevice corrosion under backing rings, in threaded joints, in socket welded joints, and in other stagnant, confined areas
- The possibility of adverse electrolytic effects if the metal is subject to contact with a dissimilar metal
- The compatibility of lubricants or sealants used on threads with the fluid service
- The compatibility of packing, seals, and O-rings with the fluid service
- The compatibility of materials, such as cements, solvents, solders, and brazing materials, with the fluid service
- The chilling effect of sudden loss of pressure on highly volatile fluids as a factor in determining the lowest expected service temperature
- The possibility of pipe support failure resulting from exposure to low temperatures (which may embrittle the supports) or high temperatures (which may weaken them)
- The compatibility of materials, including sealants, gaskets, lubricants, and insulation, used in strong oxidizer fluid service (for example, oxygen or fluorine)
- The possibility of adverse effects from microbiologically influenced corrosion (MIC) or its remediation

And with regard to the selection of material for systems that fall under the rules for ASME B31.3 High Pressure piping, things become much more complicated. For a high-pressure system, you will not only take into consideration material compatibility with the fluid service, but will also need to consider the effect of high pressure, we'll say, as an order of magnitude, in excess of 1,000 psig, on the material itself in conjunction with the design temperature.

At higher pressures or elevated temperatures, or both, you will need to assess the risk to the selected material for such concerns as hydrogen embrittlement as well as items of concern listed in ASME B31.3, paragraph K302 Design Criteria for high pressure piping. Those concerns include the following:

- Tensile, compressive, flexural, and shear strength at design temperature
- Fatigue strength
- Design stress and its basis
- Ductility and toughness
- Possible deterioration of mechanical properties in service
- Thermal properties
- Temperature limits
- Resistance to corrosion and erosion
- Fabrication methods
- Examination and testing methods
- Hydrostatic test conditions
- Bore imperfections

And while the material selection process, as discussed, pertains to a piping system as an example, it can also be applied to process vessels and other equipment, with one glaring exception. The rules for pressure vessels are much broader and much more specific and demanding than the rules for piping. The dynamics that have to be considered when selecting material for equipment are different, and the fabrication rules are much different and varied than they are for piping.

Material cost

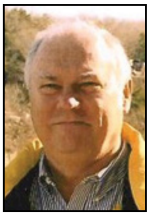
The last thing to be considered will be the installed cost of the selected MoC. The installed cost is the last thing to be considered because the safety and integrity of a process system is first and foremost in the selection process. And once the selection has been decided upon for compatibility, safety and integrity, and you are left with multiple materials, including nonmetallic materials, it then comes down to the installed cost.

Including the installed cost can actually move the needle from a low front-end cost for a material that may be more costly to install to a material that has a higher front-end cost, but may be less costly to install. So, when making that final decision on which material to go with, base it on the total installed cost, not the base material alone.

The material selection process discussed in this article is explained in a rather straight-forward and simplified manner, but the process itself, and all that it entails, in all actuality should be carried out by an individual with years of experience in the CPI — someone with a history of working with the various materials and fluid services used in this industry. ■

Edited by Gerald Ondrey

Author



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Standard Operating Procedures are Critical for Boiler and Steam Operations

An overview on the importance of standard operation procedures (SOPs) and how to write them

Kelly Paffel
Inveno Engineering, LLC

Today, it is necessary to have standard operating procedures (SOPs) for steam and condensate systems, boilers, deaerators and even steam process units (Figure 1). An SOP is a set of instructions or steps that someone follows to complete a job safely, prevent premature failures due to improper startup or shutdowns, and maximize operational and system performance.

SOPs are important because they memorialize key steps in processes and avoid problems. Having plant personnel start up a steam system without an SOP and assuming that the result will be positive is just being hopeful. A boiler or steam system contains a large amount of stored energy. Having a problem occur during startup and releasing that uncontrolled energy can pose a major safety risk and hurt the plant operation.

Moreover, if a person were to interview 10 people, as our engineering team has done, on how to properly start up a pressure-reducing station, they are likely to hear 10 different answers.

SOPs also improve consistency. Take, for example, how a plant trains new staff members how to start up a boiler. Having a lead employee teach a new employee is not very effective, because people typically retain less than 42% of the instructions. This leaves new staff members assuming how to do a task. Assuming is risky when dealing with steam, which can cause major damage in the event of an uncontrolled release. Therefore, it is important to write SOPs for all processes that an individual or group performs, including starting a steam line, shutting down a steam process, testing a boiler, repairing a valve, controlling a steam control valve, and even tuning a PID (proportional integral derivative) controller.

FIGURE 1. An SOP is important for properly maintaining a steam-supply system

FIGURE 2. An SOP will help ensure the proper operation of a boiler plant

For instance, the SOP for testing steam traps can be 48 pages long to ensure that everyone performs tests correctly and consistently, so the test results are extremely accurate.

SOPs can also reduce costly problems. As an example, root-cause analysis shows that a significant percentage of premature failures in the steam system result from improper startup that causes water hammer, damaging the components in the steam system. Production issues at startup often result from the fact that no one is given an SOP on how to properly vent air or ensure that condensate is properly removed from the system. Air in the steam system is detrimental to process operations.

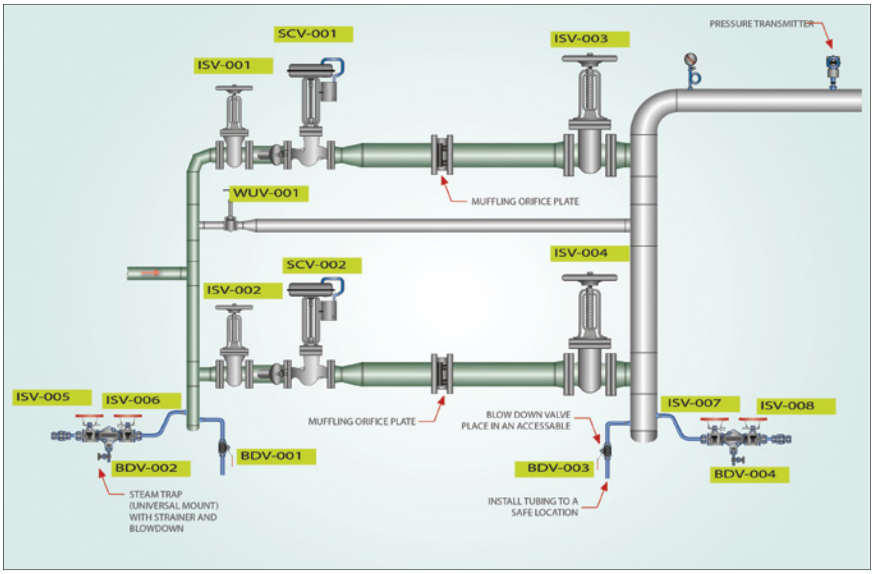

FIGURE 3. Shown here is an example of valve numbering for an SOP

Why write an SOP?

The following are ten of the most important reasons that every steam or boiler plant (Figure 2) needs to develop a set of SOPs:

1. Providing plant personnel at all levels who perform operational tasks with all the safety, health, environmental and operational information required to perform a job properly
2. Protecting the safety of plant personnel and plant process applications
3. Ensuring that operations are done consistently to maintain the safe, reliable startup or shutdown of a boiler or steam system
4. Ensuring the SOP tasks are completed on a prescribed roadmap throughout the operation, thus leading to successful task completion
5. Avoiding failures in the system and related processes that would cause operational issues
6. Ensuring approved procedures are followed to comply with ASME codes, industrial best practices and standards, and company standards
7. Protecting product quality and achieving production goals
8. Providing a great training document for teaching current plant personnel and new plant personnel
9. Serving as a historical record of the how, why and when of a task in a system to use when modifications are made to that system and when an SOP must be revised
10. Building a tool that explains the different steps or tasks in a process that can be reviewed in post-incident investigations to improve safety practices and system operating conditions

How to write an SOP

A good SOP is brief. It should describe the necessary tasks and steps in a way that is easy to understand and implement.

When writing an SOP, remember the following five points:

Involve the necessary plant personnel. Writing an SOP should be a team effort. The writing team needs to make sure that the right plant personnel are involved in the SOP process. At least one team member must be intimately familiar with the task outlined in the SOP. That person will understand exactly what needs to be done to successfully complete the task and could have important insight and suggestions on ways to improve the SOP. Remember, an SOP is only helpful if the team members executing the task can understand what is written.

Assuming is the wrong approach. One of the biggest mistakes that the writing team can make when writing the SOP is assuming that the team members executing the tasks are familiar with each task, its steps, or even a concept that is not documented or defined in the SOP. Thinking that an employee who has been working with the steam system for 22 years knows how to accomplish the task correctly and safely is the wrong approach.

When the team is writing the SOP, it is better to overinform than to provide too little information. When the writing team leaves out certain things, it could be the beginning of a serious problem.

A glossary or term list can be very helpful when the writing team is creating an SOP. The team members doing the tasks can use the glossary to learn more information about specific items, tasks and concepts.

Including items like steam traps, control valves and safety valve tag numbers in an SOP allows team members to ensure the correct component is being operated (Figure 3).

Pictures, visual images and CAD prints are helpful. An SOP should not be a long document that is only full of text. The writing team will want an SOP to be informative and concise above all else. Using pictures, visual images, CAD prints, and so on can help create an excellent SOP. Visual aids back up the SOP text and make the content more meaningful.

Using imagery can also help make SOPs more accessible to people. Some people are visual learners who process information better from visual aids than from written material.

It Is critical to test the SOP. The writing team needs to test an SOP's steps before making the tasks or steps any part of an official SOP process. Walking through the process of accomplishing a task creates an easy roadmap for the writing team to see how things are currently working and whether anything can be done to improve things before drafting the final SOP. The writing team may find that something everyone assumes is well known should be documented in the SOP.

An SOP is never final. The SOP is a living document. It should continue to be improved upon and revised to meet the changing requirements of the plant operation. ■

Edited by Gerald Ondrey

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Minimizing the Effects of VOCs and Reactive Gases on Industrial-Grade LED Lighting

Chemical plants should not overlook the potential problems that can arise from damaged or malfunctioning lighting fixtures

Fariyal Khanbabi
Dialight

It is no secret that many chemical plants and industrial sites are prone to harsh environmental conditions that can wreak havoc on equipment and lighting. Because lighting directly supports plant safety and operations, it is among the most critical pieces of equipment in any facility (Figure 1). However, vibration, excessive heat, humidity and power fluctuations are just a few examples of the culprits that can chip away at the lifespan and performance of safety-critical lighting.

FIGURE 1. Industrial lighting is a critical part of any manufacturing site. However, aggressive environmental conditions can cause damage to lights, which may often go unnoticed

Constant vibration of continuously operating heavy machinery can violently shake lighting fixtures apart, and conventional lighting sources with fragile filaments and bulbs are among the most vulnerable to damage due to heavy vibration.

The high temperatures present at industrial work sites can be a result of anything from process equipment and heavy-duty motors to molten raw materials. If proper thermal management and heat-resistant components are lacking, excessive heat will quite literally fry the electrical components in fixtures that are not specifically designed to hold up in these conditions.

Moisture is also a constant problem in many facilities, causing corrosion and degradation of metal structures, with salt spray being one of the worst offenders. Highly corrosive conditions can degrade fixture components and hardware, compromising the integrity of the light fixture itself, as well as its secure mounting. That means not only is the fixture at risk of frequent failure, but also of falling and hurting someone or damaging other equipment. Despite the best efforts of seasoned electrical professionals, chemical-intensive environments are notorious for unstable power conditions — namely, in the form of surges and sags caused by heavy equipment startup and shutdown, along with other conditions that cause power to fluctuate. This unpredictability can overstress power supplies that are simply not built for these unruly conditions. The constant voltage fluctuations will cause excess heat, eventually frying the internal circuitry and causing unexpected and premature fixture failure.

But among the most elusive causes of failure for plant lighting performance — and among the most difficult to protect against — are volatile organic compounds (VOCs) and reactive gases. Not only are these pervasive in facilities, but up until recently, there were little to no proven solutions to protect industrial lighting from their impact.

While most of the time the presence of VOCs goes completely undetected, over time, these materials can have a devastating effect on lighting and facility safety in two ways. First, they can be highly volatile and prone to explosion or ignition in the presence of high heat or electric spark. Second, they can cause chemical degradation of light-emitting diodes (LEDs) and other electronic components, resulting in color shifting or lumen depreciation, which can affect visibility and the clear illumination of hazards.

Because VOCs are difficult to detect and prevent in such severe environments, many plants underestimate the risk to employee safety. Since up until recently technology specifically designed to protect against these effects didn't exist, lighting fixtures were frequently treated as cheap and disposable, driving up facility and plant maintenance costs.

Despite these challenges, with a few strategies and identification of the hazards present, plant managers can choose lighting that is designed to protect against these issues, prioritizing employee safety and ensuring the longevity of their fixtures.

No facility is immune

VOCs and reactive gases are everywhere, but concentrations can be up to ten times higher in indoor

FIGURE 2. Especially in harsh industrial environments, it is crucial that lighting fixtures be outfitted with protective features that make them more resilient against reactive gases and VOCs

structures. Elevated temperatures promote their release, causing them to coat virtually any surrounding surface. Similar to VOCs, reactive gases like hydrogen sulfide, sulfur dioxide and chlorine are also emitted through various maintenance processes. Once a person perceives that there is an environmental problem, it is usually past the damage threshold for corrosion of electronic modules, especially in the hot and humid areas common in plant settings. The challenges are often more complex when electrical systems, such as lighting lenses and wires, as well as fluorescents and high-intensity diodes (HIDs), are exposed. Such exposure leads to corrosion of individual electrical components, causing flicker, premature fixture failure and other avoidable hazards.

Unfortunately, the industry tends to focus on controlling current and LED temperatures within the fixtures, while running the risk of missing other factors that can directly affect the performance of the LEDs over time. Even the most securely enclosed LED fixtures are not immune, because VOCs can permeate silicone-based seals, discoloring the diode surface itself, ultimately resulting in decreased light output and color shifting, which diminishes visibility. Since the root cause of the loss of performance is the VOC, the change is reversible. The LED device can revert to normal performance if the VOC escapes a ventilated luminaire.

While evidence from multiple tests and studies have proven that sensitive electronic areas treated with protective coatings are significantly better protected than uncoated areas, component manufacturers have not commercialized protections to prevent these failure modes. This has prompted some fixture manufacturers to engineer advanced methods to protect fixtures from the impacts of VOCs and reactive gases.

Prioritizing lighting and safety

According to the 2022 In-House Facility Management Benchmarking Survey Report, health, safety and improving facility and building image and security are the most important issues for plant managers and service contractors [*1*]. Unfortunately, the impact of VOCs and reactive gases on lighting can make achieving these goals extremely difficult. Aside from the safety and security risks, failure to keep lighting and electrical systems in good working order can even result in costly city or county penalties, regulatory infractions and even plant closures.

Inadequate lighting, exposed electrical parts and corroded fixtures from VOCs and other environmental conditions put workers at risk. Faulty electrical fixtures alone account for 52% of fatalities, with the Occupational Safety and Health Administration (OSHA; Washington, D.C.; www.osha.gov) continuing to identify poor lighting as a leading cause of injuries [*2*]. Over the past decade alone, these accidents have cost companies billions of dollars in medical and compensation expenses [*3*]. Worse yet, thousands of these accidents have resulted in loss of life, all of which could be prevented with better, more resilient lighting.

Providing a well-lit, vibrant work environment is essential for maintaining facilities and plants and improves overall building reputation and security. When overall illumination is increased, accident rates decrease by as much as 60%, making it easier to perform work that requires precision and pay attention to detail [*4*]. Improved lighting can also dramatically improve the clarity of closed-circuit camera systems, enhancing security [*5*]. But with constantly vibrating machinery and VOCs and reactive gases in the atmosphere affecting the reliability and performance of fixtures, keeping up with lighting and electrical maintenance is a never-ending chore. In one instance, not only were various fixtures causing immense maintenance for a petrochemical plant, but it also required the regular purchasing and storage of a wide range of delicate bulbs and ballasts [*6*]. It is also extremely expensive, with 91% of facilities bearing the burden of bulb replacement in-house [*1*].

Between the specialized equipment needed to reach high-mounted fixtures, the rewiring requirements for overloaded circuits and the need to keep plenty of replacement bulbs on hand for a wide range of fixture models, it can cost hundreds of thousands of dollars per year just to maintain a building's lighting.

Upgraded lighting pays off

Well-made industrial LED fixtures often feature custom power supplies with optimized thermal dissipation for protection against a variety of environmental conditions and vibration related failures. They typically last an average of up to 10 years and are easy to install and retrofit to existing infrastructure, providing longer-life performance with near-zero maintenance to lower the risk of accidents related to poor visibility.

Most recently, lighting fixtures and equipment have evolved to include new features that are designed to be resilient to VOCs and reactive gases, such as VOC-resistant coatings, along with noble-metal electrical contacts and protected conductive joints to resist corrosion and prevent VOCs and other chemicals from permeating through

(Figure 2). This ensures that the lights stay on and their electrical components remain secure, all while delivering optimal output and visibility, even in the harshest environments. Upgrading facility lighting fixtures to high-efficiency, high-durability lighting such as VOC-shielded LED fixtures can drastically improve overall employee safety and productivity, while decreasing control costs. As an added bonus, investing in resilient LED fixtures can also help chemical plants and industrial work sites to place a strong emphasis on operational efficiency, sustainability and reduce overall emissions. In addition to their long-life performance, LED fixtures can cut electrical consumption and greenhouse gas emissions by as much as 90% compared to conventional fixtures. All of this makes investing in upgraded lighting a win for safety, security and sustainability. ■

Edited by Mary Page Bailey

References

1. CMM 2022 In-House/Facility Management Benchmarking Survey Report, *Cleaning & Maintenance Management*, March 2022.
2. OSHA, Slips, Trips and Falls: Identification and Prevention, presentation from December 2018.
3. Leigh, J. Paul, Economic Burden of Occupational Injury and Illness in the United States, *Milbank Q.*, December 2011.
4. Case Study: Donjon Shipbuilding and Repair, Pennsylvania, Dialight, December 2015.
5. New Jersey Wastewater Facility Overhauls Lighting, *Water World*, May 2022.
6. Case Study: OQ Chemicals' Plant in Bishop, Tex., Dialight, Feb. 2021.

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Show Preview

The HydrogeNext conference is taking place August 16–17 in Savannah, Ga. as part of the larger Experience Power Week event (www.experience-power.com). Hydrogen is expected to play a major role in decarbonizing global energy systems, and the technical sessions and panel discussions at HydrogeNext will explore the full hydrogen value chain, from production to distribution and end-use. Attendees will benefit not only from HydrogeNext's comprehensive technical conference program, but also the full slate of activities of Experience Power, including a large exhibition hall featuring hands-on technology demonstrations, numerous networking opportunities and the option to attend two other co-located technical conferences — the Distributed Energy Conference and Electric Power Insights. Below is the HydrogeNext conference program.

WED. AUGUST 16

But First, a Safety Moment
This session focuses on some unique safety issues that the hydrogen industry is facing, including challenges related to pipelines and enclosures.

Hydrogen Materials Supply Overview
With so many factors affecting the supply chain, one must stop to think about issues around material availability as the industry looks to increase hydrogen production. This session will provide an overview of areas to focus on as this industry grows.

Alkaline, PEM, AEM, Oh My — So many ways to produce hydrogen
This session will include a deep dive into several different electrolyzer technologies and review the engineering specifics to understand the nuances of their utilization in industry

Hydrogen in the Real World — A Look at Emerging Projects and Applications
This session will showcase several projects that are currently underway to test and develop hydrogen technologies, with input from project leaders about the challenges and opportunities they are facing and the projects' impact on the future economy.

Overcoming Challenges in Utilization, Purification and Water Usage
There are many pieces to the renewable-hydrogen puzzle, including balancing the technological demands of hydrogen production and utilization with the abilities of current technologies for combustion, purification and separation of hydrogen and related products, such as ammonia. The session will also address some of the requirements related to water demand for hydrogen production.

THU., AUGUST 17

Financial Metrics of Hydrogen Projects
In order for hydrogen to be adopted at scale, it needs to be financially viable. This session will explore the financial metrics behind hydrogen projects, including lifecycle analysis, storage, transportation and project viability. Speakers will discuss the factors that make hydrogen projects successful and provide insights into how to make projects more financially attractive.

Hydrogen — the Electrification Alternative
This session will discuss the benefits of hydrogen, the challenges that need to be overcome on the path to electrification, including hydrogen distribution, and how large-equipment manufacturers are repurposing reciprocating engines to utilize hydrogen.

Hydrogen Hubs — Accelerating the Use of Hydrogen as a Clean Energy Source
Hydrogen hubs are clusters of hydrogen production, storage and demand. They are being developed around the world as a way to accelerate the use of hydrogen as a clean energy source. This session will feature speakers from several hydrogen hubs discussing their concept activities, opportunities, adjacent projects, seed markets and connections. They will cover the challenges and opportunities of developing hydrogen hubs, and the potential for hydrogen to play a role in the clean energy transition. ■

Mary Page Bailey

HYDROGENEXT

Courtesy of Josh Gold Photography

Decarbonization

special advertising section

CHEMICAL ENGINEERING
ESSENTIALS FOR CPI PROFESSIONALS

Access Intelligence

Technologies that capture your attention

Sulzer Chemtech's separation technology is at the core of successful, value adding carbon capture projects

Advanced process solutions are key to helping chemical process industries (CPI) develop and implement successful decarbonization strategies. To facilitate the adoption of more sustainable practices, Sulzer Chemtech offers a complete mass transfer solution portfolio that is designed to support highly effective carbon capture, utilization and storage (CCUS) facilities.

With a proven track record of delivering advanced CCUS solutions of any scale, the leader in separation and mixing technology has developed world-class equipment for such processes. The ever-expanding range of solutions available is engineered to maximize the removal of carbon dioxide (CO_2) from flue gases with high efficiency while preventing the loss or emission of solvents into the atmosphere. As a result, environmentally oriented players in the CPI can reduce the costs and environmental impact associated with CCUS operations.

Manufacturers and processors can leverage MellapakCC structured packing to set up compact yet highly effective separation units, with achievable capture efficiencies between 90 and 99%. This column component also significantly reduces pressure drops, optimizing the efficiency of amine absorption units. Thanks to all these features, annual costs of CCUS operations processing 1'000 tonnes or more per day of flue gas that leverage MellapakCC are expected to be well below EUR 45 per tonne of CO_2 captured.

This customized packing for CCUS can also be combined with highly efficient MellaTech liquid distributors and AYPlus DC column internals. These help to properly distribute and prevent the loss and emission of amine-based solvents. As a result, it is possible to optimize solvent utilization, recovery and ultimately the sustainability of CCUS operations. Besides, Sulzer Chemtech is helping companies integrate cost-effective excess heat solutions for solvent regeneration to further enhance these benefits.

Thanks to Sulzer Chemtech's expertise and state-of-the-art separation technologies, players in key industries have been able to turn CCUS facilities into profitable plants to generate new revenue streams. Even more, Sulzer Chemtech is helping customers develop innovative carbon utilization solutions to drive circularity.

Find out how Sulzer Chemtech's technologies and engineering solutions for decarbonization are being leveraged to slash emissions while driving quick returns on investment at **www.sulzer.com.**

GEA is making decarbonization a reality.

With cutting-edge carbon capture technologies and innovative CO_2-reducing processes, GEA helps its customers to smoothly transition into the low-carbon economy.

To meet climate and global warming targets, the way humanity consumes and produces must change. Across industries, an array of options has been gaining traction on the race to achieve carbon neutrality but there is no one-size-fits-all solution.

GEA´s portfolio for processes decarbonization offers made-to-measure solutions and a multi-pronged approach, adaptable across the chemical process industries and beyond. Helping customers reduce harmful emissions while improving their energy efficiency and facilitating their journey towards carbon neutral production.

As a worldwide leading provider for air pollution control solutions, GEA offers not only its well-established gas cleaning and heat recovery technologies but also an amine-based CO_2 capturing processes along with options for CO_2 transport, utilization and sequestration.

These technologies for Carbon Capture and storage (CCS) enable the separation of CO_2 from emission points before it gets released into the atmosphere for its posterior use in the production of valuable CO_2-based products or to sequestrate it in long-term storages. An effective and attractive option for highly CO_2-emitting industries that has allowed GEA´s air pollution solutions portfolio to expand and have an ever more significant impact.

Another way in which GEA is leading the way towards decarbonization is by doing its part to help meet the demand for power from "clean" energy sources through a lithium portfolio that starts at the mine and goes beyond the dried battery powder. It includes the solvent recovery during battery production and supporting in closing the loop with recycling the batteries with extraction and purification of critical metals such as cobalt, lithium and nickel.

Rechargeable li-ion batteries have come to open the door to low-carbon connectivity and mobility that can reduce pollution while creating jobs, making streets safer, strengthening infrastructure and stimulating local economies — it is no wonder, that their demand is on a sustained rise. As an established one-stop-supplier for all major lithium process steps, GEA´s portfolio includes evaporative concentration, precipitation, crystallization, purification, separation and drying,providing its customers with an unrivalled combination of process expertise that covers the whole spectrum of lithium production, from brine concentration to high-purity particles.

Lithium processing? GEA has you covered. **www.gea.com/en**

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See bottom of opposite page for advertising sales representatives' contact information

Classified Index August 2023

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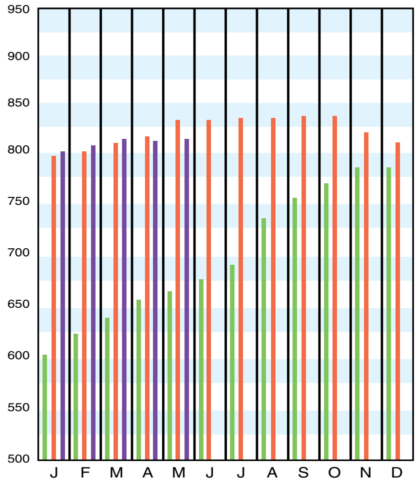
Economic Indicators

2021 2022 2023

Download the CEPCI two weeks sooner at www.chemengonline.com/pci



CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	May '23 Prelim.	Apr. '23 Final	May '22 Final
CE Index	809.4	803.3	831.1
Equipment	1,022.0	1,014.3	1,056.4
Heat exchangers & tanks	841.6	832.8	898.9
Process machinery	1,033.8	1,041.8	1,075.3
Pipe, valves & fittings	1,400.7	1,397.5	1,494.7
Process instruments	564.9	567.2	575.0
Pumps & compressors	1,448.0	1,387.9	1,273.3
Electrical equipment	796.7	796.5	756.6
Structural supports & misc.	1,147.6	1,128.3	1,177.7
Construction labor	365.6	362.9	354.3
Buildings	817.9	808.5	847.4
Engineering & supervision	313.9	313.8	311.5

Annual Index:

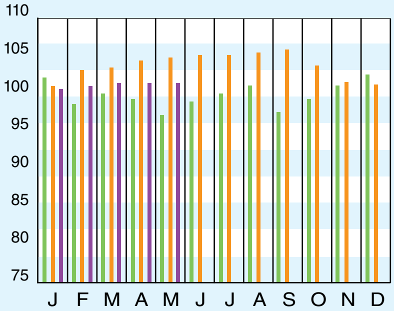
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.8
2022 = 816.0

Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

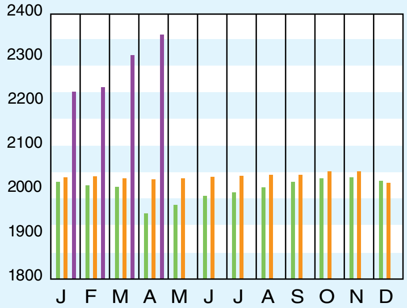
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (2017 = 100)	May '23 = 99.8	Apr. '23 = 99.8	Mar. '23 = 99.4	Apr. '22 = 101.2
CPI value of output, $ billions	Apr. '23 = 2,361.3	Mar. '23 = 2,360.3	Feb. '23 = 2,421.0	Mar. '22 = 2,478.1
CPI operating rate, %	May '23 = 79.7	Apr. '23 = 79.8	Mar. '23 = 79.5	Apr. '22 = 81.8
Producer prices, industrial chemicals (1982 = 100)	May '23 = 323.2	Apr. '23 = 328.6	Mar. '23 = 326.7	Apr. '22 = 374.2
Industrial Production in Manufacturing (2017 =100)*	May '23 = 100.1	Apr. '23 = 100.0	Mar. '23 = 99.1	Apr. '22 = 100.4
Hourly earnings index, chemical & allied products (1992 = 100)	Apr. '23 = 219.8	Mar. '23 = 216.9	Feb. '23 = 210.7	Mar. '22 = 200.6
Productivity index, chemicals & allied products (1992 = 100)	May '23 = 91.7	Apr. '23 = 91.6	Mar. '23 = 92.5	Apr. '22 = 91.6

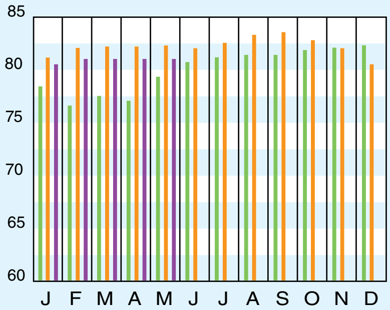
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for May 2023 (most recent available) is higher than the previous month's value. The rise is the second consecutive increase. In May, upticks were observed in all four subindices — Equipment, Buildings, Construction Labor and Engineering & Supervision. The current CEPCI value now sits at 2.6% lower than the corresponding value from May 2022. Meanwhile, the Current Business Indicators (middle) show no change in the CPI output index for May, and a slight decrease in the CPI operating rate for May, as well as a small increase in the CPI value of output for April 2023. Also, producer prices for industrial chemicals fell in May.